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AIR FORCE GEOPHYSICS LABORATORY

REPORT ON RESEARCH
For the Period July 1976 - December 1978

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This report continues a series of eight Reports on Research at the Air Force Geophysics Laboratory. This report covers a two-and-one-half-year interval. It was written primarily for Air Force and DOD managers of research and development and more particularly for officials in Headquarters Air Force Systems Command, for the Director of Laboratories (DL), and for the Commanders of and the Laboratories within DL. It is intended that the report will have interest to an even broader audience.

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Block 20, continued

For this latter audience, the report, by means of a survey discussion, attempts to relate the programs to the larger scientific field of which they are a part. The work of each of the Divisions is discussed as a separate chapter. Additionally, the report includes an introductory chapter on AFGL management and logistic activities related to the reporting period. A listing of the publications of each Division during the period follows the chapter describing the research.

Accession For

By

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AFGL-TR-80-0365

Report on Research at AFGL

JULY 1976 — DECEMBER 1978

SURVEY OF PROGRAMS AND PROGRESS

THE AIR FORCE GEOPHYSICS LABORATORY

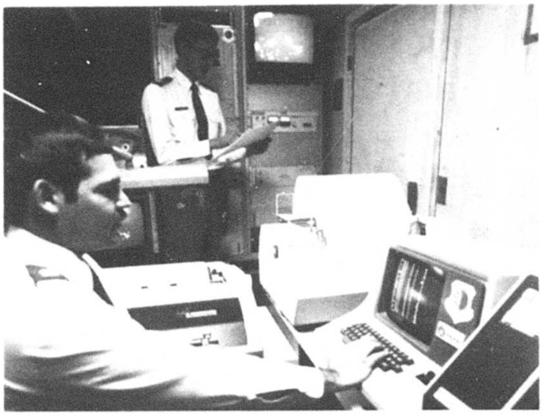
AIR FORCE SYSTEMS COMMAND

HANSCOM AIR FORCE BASE, MASSACHUSETTS

AUGUST 1980

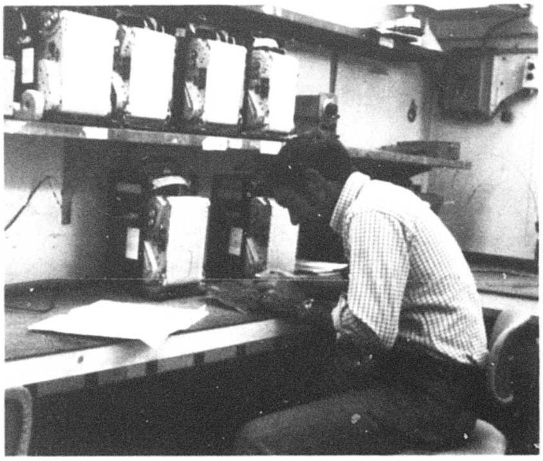
AIR FORCE (1) JULY 25, 1980 - 1500

Foreword



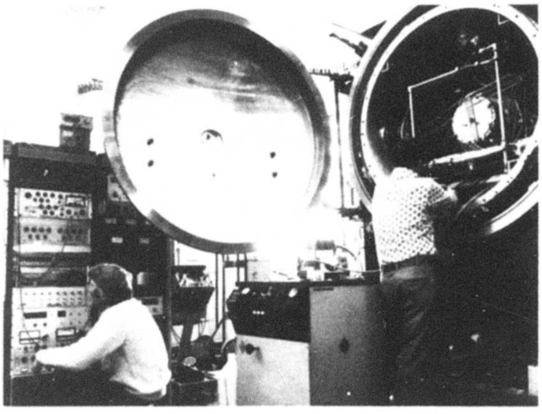
The Air Force Geophysics Laboratory (AFGL) *Report on Research* is a continuation of a series published by AFGL's predecessor organization, the Air Force Cambridge Research Laboratories (AFCRL). The Air Force redesignated AFCRL to AFGL on January 15, 1976, in order to focus attention and effort into geophysics research and exploratory development.

The report reflects the strength and breadth of the AFGL scientific program in geophysics and its satisfaction of Air Force technological and/or system needs for geophysics R&D. It is written for DOD managers of research and development as well as the scientific community. It is a biennial report and documents progress and on-going programs during the period July 1976 through December 1978.



James E Baker

JAMES E. BAKER
Colonel, USAF
Commander



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I AIR FORCE GEOPHYSICS LABORATORY

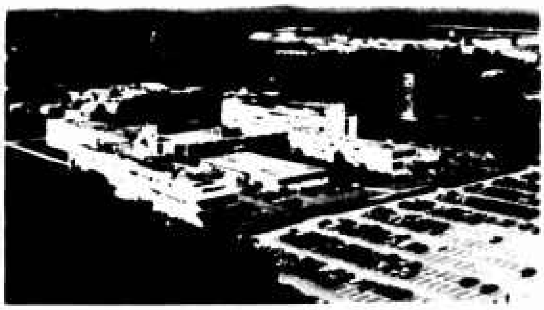
The Air Force Geophysics Laboratory came into being on January 15, 1976, by redesignation of its predecessor, the Air Force Cambridge Research Laboratories. This change reflected the Air Force policy of naming organizations according to their mission, and was made possible when the Microwave Physics Division, the Solid State Sciences Division, the Electromagnetic Environment and Ionospheric Radio Physics Branches of the Ionospheric Physics Division, and the Laser Physics Branch of the Optical Physics Division were transferred from AFCRL to the Rome Air Development Center, becoming RADC's Detachment 1, the Deputy for Electronic Technology. The remaining personnel and programs at AFGL are now devoted to exploratory and advanced development in those areas of geophysics which will meet known and anticipated military requirements. This report describes the programs, activities, and accomplishments of the organizations now comprising the Air Force Geophysics Laboratory for the period July 1, 1976, to December 31, 1978.

AFGL conducts technical programs covering a broad spectrum of disciplines in the environmental sciences. It is an in-house laboratory with a professional staff of 311 scientists and engineers. Its in-house programs are augmented by research conducted in universities and industry under contracts funded by the Air Force Office of Scientific Research (AFOSR). The programs of AFGL are summarized in the mission statement: Conducts research, exploratory and advanced development in those areas of the environmental sciences offering the greatest potential to the continued superiority of the Air Force's operational capability; participates in establishing advanced technologies whose exploitation will lead to new Air Force capabilities.

Organization and People: AFGL is one of 11 laboratories and allied organizations under the Director of Science and Technology, Headquarters, Air Force Systems Command, at Andrews AFB, Maryland. When AFCRL was merged into the Air Force Systems Command, the move was intended to focus its research and development activities more directly on evolving Air Force systems, technology, and research requirements. AFCRL's efforts had been coupled with both immediate and long-range Air Force needs, and a firm and extensive data and technology base was developed. Continuing pressure on the Air Force budget has resulted in a need to utilize the available expertise in solving user-command problems, concentrating on those areas where technology can have the most rapid impact on the operational Air Force.

In the aftermath of the 200-position Reduction in Force imposed on June 30, 1976, the Laboratory sought to apply the skills of those employees transferred to new positions to new assignments as rapidly as possible, and to direct its most vigorous efforts toward serving the needs of those elements in the Systems Command which were its principal customers. The Space and Missile Systems Organization was the largest user of AFGL's technology.

The six technical Divisions transferred to form AFGL in 1976 continued throughout this reporting period. These are the Aeronomy Division, Aerospace Instrumentation Division, Meteorology Division, Optical Physics Division, Space Physics Division, and the Terrestrial Sciences Division. In addition, AFGL operates a small West Coast Office to focus AFGL support to the technology requirements and system development efforts of the AFSC Space and Missile Systems Organization (SAMSO), near Los Angeles.



The AFGL laboratory complex is located 17 miles west of Boston at Hanscom AFB, Massachusetts, where it is a tenant of AFSC's Electronic Systems Division.

The main AFGL laboratory complex is located at Hanscom AFB, Bedford, Massachusetts, 20 miles west of Boston. At Hanscom AFB, AFGL is a tenant of the Electronic Systems Division of the Air Force Systems Command.

Colonel Bernard S. Morgan, Jr., commanded AFGL during this entire reporting period, having assumed command in January 1974. Colonel Donald R. Wipperman, who had been Vice Commander since July 31, 1973, retired on October 1, 1976. He was succeeded by Colonel Chester G. R. Czepyha, who came to AFGL from AGMC. Col. Czepyha remained as Vice Commander through the rest of the report period.

In December 1978, 81 AFGL employees held the doctor's degree, 93 held master's degrees, and 124, bachelor's degrees. AFGL scientists are active in their respective professional societies. One scientist served as Editor of *Applied Optics* during the reporting period. Another was the Alternate U. S. Delegate to the Solar-Terrestrial Physics Group of the Pan-American Institute of Geography and History. Other AFGL scientists served as Associate Editors and referees for various professional journals, served on professional committees, and chaired professional meetings and symposia.

Examples of this type of activity include the Chairman of Working Group 4 of the Committee on Space Research, Chairman of the International Radiation Commission's Working Group on a Standard Radiation Atmosphere, and the Commander, who served on the editorial boards of the *Journal of Dynamic Systems, Measurement and Control*, and *Computers in Mathematical Sciences with Applications*.

During the 2½ years covered by this Report, AFGL sponsored two, and co-sponsored one, scientific conferences. AFGL scientists and engineers authored 297 articles in scientific and professional journals, presented 326 papers at technical meetings, and wrote 207 in-house reports. These publications and presentations are listed at the conclusion of each division chapter.

Annual Budgets: The annual budgets for the 2½ years covered in this report are shown in the accompanying tables. The totals cover salaries, equipment, travel, supplies, computer rental, service contracts, and those funds going into contract research. The largest expenditure is for contract research and equipment. Reflecting the division of AFCRL into AFGL and RADC/ET in the middle of the fiscal year, the budget decreased from $60 million in FY 1976 to $44 million in FY 1977. It then increased to $50.4 million in FY 1978 and declined slightly, to $50 million in FY 1979. This reporting period saw a change in the way the money was spent. Although salaries had always been the largest single item in the past, contract research became the largest single item in the budget after FY 1976. The amount fluctuated with the budget, decreasing from $25.8 million in FY 1976 to $22.7 million in FY 1977, increasing to $28.5 million in FY 1978, and declining in FY 1979 to $27.3 million. Salaries followed a steadier course, changing from approximately $34 million in FY 1976 to $21.7 million in FY 1977, to $21.9 million in FY 1978, and to $22.7 million in FY 1979. The large drop from FY 1976 to FY 1977 was caused by the separation of RADC/ET from AFGL and the Reduction-in-Force completed at the end of FY 1976.

At the same time, the Air Force implemented a policy of having 70 percent of the basic research performed by universities, and only 30 percent done in-house. Because Air Force research needs were perceived as changing very much faster than the interests of any organization with reasonably stable employment, this ratio was seen as necessary. Over several years of declining budgets, this ratio had been reversed to 70 percent in-house basic research and 30 percent University basic research. This reversal was the largely accidental response to a series of budget cuts as Laboratory managers cut where they could while trying to keep their organization reasonably stable.

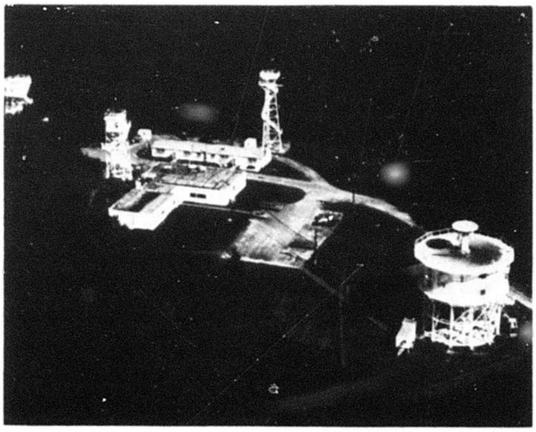
The Air Force Office of Scientific Research was designated the Single Manager of all basic research within the Air Force. In carrying out this role, AFOSR reviewed all proposed basic research, and funded selected Laboratory and University projects, maintaining the 70 - 30 ratio that Air Force Headquarters had directed.

The $28.5 million spent on contract research in FY 1978 was divided among 204 contracts. Of these, 106 were with U. S. universities, 87 with U. S. industrial concerns. The remaining 11 were with foreign universities, research foundations, and other government agencies.

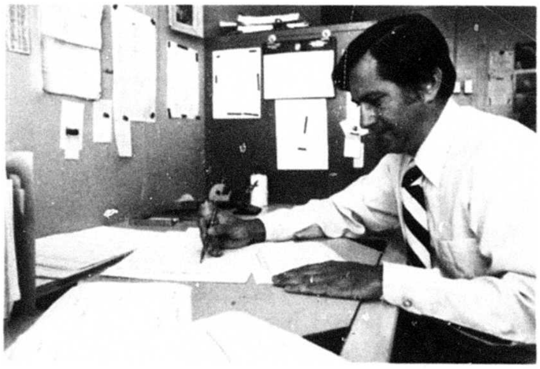
AFGL contracts almost always call for work in the direct support of the engineering and development carried out within AFGL. They are monitored by scientists who are themselves active, participating researchers, and who plan the research, organize the program, interpret the results, and share the workload of the actual research.

Funds received from AFGL's higher headquarters, the AFSC Director of Science and Technology (DL), and to a lesser extent, those received from AFSC organizations other than DL, are used to conduct continuing programs.

AFGL receives support from the Electronic Systems Division, the host organization at Hanscom AFB, in accounting, personnel, procurement, security, civil engineering, and supply to the laboratory complex. Holloman AFB, New Mexico, provides services to the AFGL Balloon Detachment. AFGL provides support to RADC's Deputy for Electronic Technology (ET) in the areas of the Research Library, laboratory materials needed for the ET mission, computer, technical photography, mechanical and electrical engineering of laboratory layouts, electronic instrumentation, and woodworking.



The AFGL Weather Radar Facility, at Sudbury, Massachusetts, is one of the larger off-base sites. It is used to study possible new ways to derive meteorological information from radar observations.



More than half of the 618 AFGL personnel are scientists or engineers. Of these, 80 have received the Ph.D. degree.

Field Sites: In addition to the buildings which it occupies at Hanscom AFB, AFGL operates several off-base sites, locally and at distant locations. The largest local site is the Sagamore Hill Radio Observatory at Hamilton, Massachusetts, which has an 84-foot radio telescope and several smaller telescopes. Other local sites are the Weather Radar Research Facility at Sudbury, Massachusetts, and the Weather Test Facility at Otis AFB, Massachusetts.

AFGL operates a balloon launch site at Holloman AFB, New Mexico. AFGL also maintains a seven-man branch of the Solar Physics Division at the Sacramento Peak Solar Observatory, at Sunspot, New Mexico. AFGL had operated the Observatory approximately 25 years, but ownership was transferred to the National Science Foundation on June 30, 1976.

One very remote station is the Goose Bay Ionospheric Observatory at Goose Bay Air Station, Labrador, where studies of a variety of subarctic events are made, including polar cap absorption of high frequency radio waves.

AFGL field programs utilize a number of military installations including the Fort Churchill, Canada, rocket range; Fort

Wainwright and Eielson AFB, Alaska; Albrooke AFB, Canal Zone; Travis AFB, California; Vandenberg AFB, California; and the White Sands Missile Range, New Mexico. In addition to these military sites, AFGL has used other locations on a temporary basis. Commercial airports and the Poker Flat, Alaska, range are also used.

Research Vehicles: From its permanent balloon launch site at Holloman AFB, New Mexico, and from temporary sites in several other locations, AFGL launched 146 large research balloons during the 2½ year period. Of these, 14 were launched during FY 7T, 68 during FY 77 and 57 during FY 78. In addition, 22 tethered flights were conducted. These balloons carried test and experimental payloads for the Space and Missile Systems Organization (SAMSO), the Defense Nuclear Agency (DNA), the National Aeronautics and Space Administration, the Energy Research and Development Administration (now the Department of Energy), the Army, and university scientists with military contracts. AFGL scientists themselves are, however, the largest users.

Rockets are used to examine almost every aspect of the earth's upper atmosphere and near-space environment — winds, temperatures and densities; the electrical structure of the ionosphere; solar ultraviolet radiation; atmospheric composition; the earth's radiation belts; cosmic ray activity, and airglow and aurora. The rockets most frequently used have been the Aerobee and combinations using the Nike booster, such as the Nike-Hydac.

During the past 2½ years, a total of 28 large research rockets were launched. The White Sands Missile Range was used most often (12 launches). Others were launched from Poker Flat Rocket Range, Alaska (7); Kwajalein Missile Range (5); Wallops Island, Virginia (2); and Fort Churchill, Canada (2).

During this reporting period, packages designed here were carried aboard two Air Force scientific satellites, the NASA Atmosphere Explorer D and E satellites, and the SOLRAD satellites.

AFGL Computation Center: AFGL operates a large scientific data processing facility consisting of two CDC 6600 computing systems which support AFGL, ESD, other government agencies and DOD contractors.

The CDC 6600 systems consist of a modular desugned multi-processor operation with extensive input-output devices, peripheral equipment and communications equipment. The systems provide remote batch, interactive graphics and conversational capabilities through a network of approximately 50 remote stations located within the laboratory complex and at off-base locations. The de-commutation facility processes data from satellites, rockets, aircraft, balloons and from laboratory data collection systems, using two special purpose Honeywell computer systems.

AFGL Research Library: The breadth and quality of the technical collection maintained by the AFGL Research Library are surpassed by few libraries in the country. Available to AFGL scientists are the scientific journals of Bulgaria, Czechoslovakia, the Netherlands, France, Germany, Hungary, Italy, Japan, Poland, Russia and Sweden. The collection of Chinese science journals and monographs is one of the most comprehensive in the U. S. Associated with the foreign periodical collection are translation services.

TABLE 1
SOURCES OF FY-1976 FUNDS

Air Force Systems Command - DL	$45,010,000
Air Force Systems Command - Other than DL	7,208,314
Defense Nuclear Agency	3,155,000
Defense Advanced Research Projects Agency	2,437,940
Defense Mapping Agency	1,118,000
Army	459,300
Energy Research and Development Administration	358,878
Navy	160,755
National Aeronautics and Space Administration	150,825
Air Weather Service	68,000
Sandia Laboratories	56,698
Air Defense Command	2,000
TOTAL	$60,185,710

TABLE 2
SOURCES OF FY 197T FUNDS

Director of Laboratories	$11,372,000
Other Air Force	2,123,000
Defense Nuclear Agency	572,000
Defense Mapping Agency	228,000
Defense Advanced Research Projects Agency	50,000
National Security Agency	50,000
Army	30,000
National Aeronautics and Space Administration	4,000
TOTAL	$14,429,000

TABLE 3
SOURCES OF FY-1977 FUNDS

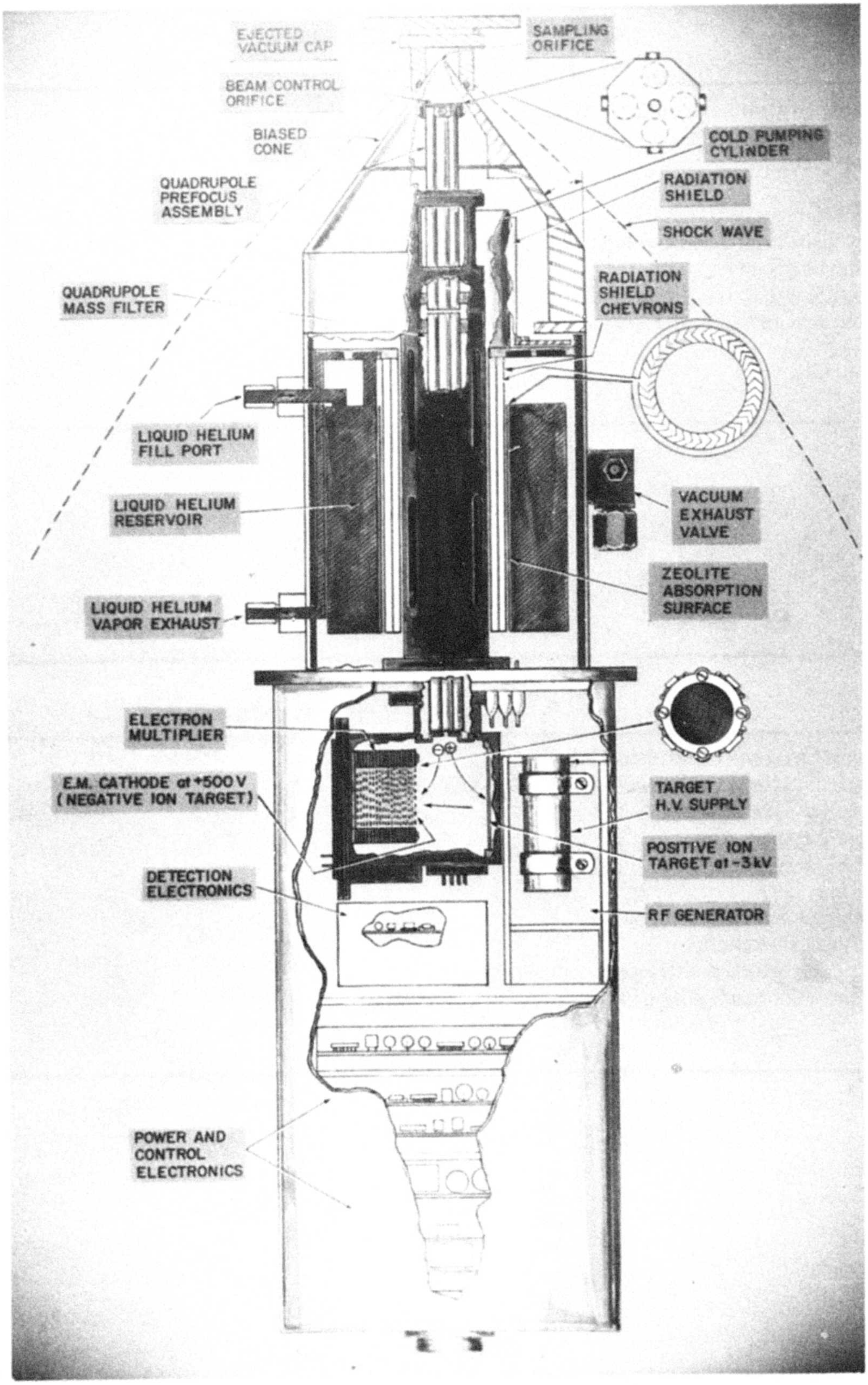
Air Force Systems Command - DL	$23,540,000
Air Force Systems Command - Other than DL	15,569,000
Defense Nuclear Agency	2,391,000
Defense Mapping Agency	962,000
Army	941,000
Energy Research and Development Command	565,000
National Aeronautics and Space Administration	163,000
Air Weather Service	85,000
National Security Agency	69,000
Navy	60,000
Other Air Force	20,000
TOTAL	$44,365,000

TABLE 4
SOURCES OF FY-1978 FUNDS

Air Force Systems Command - DL	$27,359,000
Air Force Systems Command - Other than DL	18,470,000
Defense Nuclear Agency	2,250,000
Army	898,000
Defense Mapping Agency	686,000
Energy Research and Development Administration	58[illegible]
Air Weather Service	8[illegible]
National Security Agency	50,000
National Aeronautics and Space Administration	35,000
Navy	20,000
TOTAL	$50,439,000

TABLE 5
SOURCES OF FY-1979 FUNDS

Air Force Systems Command - DL	$26,222,000
Air Force Systems Command - Other than DL	19,546,000
Defense Nuclear Agency	2,702,000
Defense Mapping Agency	775,000
Department of Energy	367,000
Army	244,000
Air Weather Service	101,000
Air Defense Command	53,000
National Aeronautics and Space Administration	27,000
Air Force Communications Service	9,000
TOTAL	$50,046,000



D region positive/negative ion mass spectrometer.

II AERONOMY DIVISION

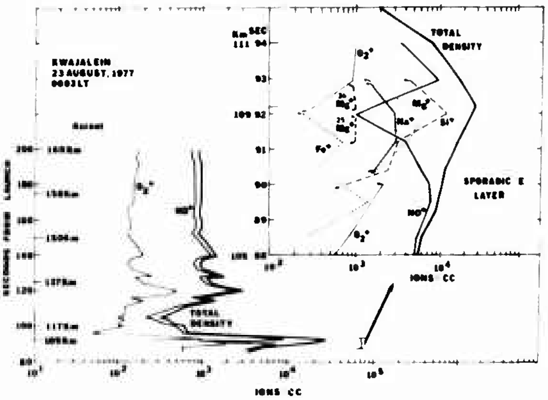
Aeronomy is the study of the physical and chemical properties of the earth's upper atmosphere. It deals principally with the atomic, molecular, and ionic composition of the atmosphere and how the composition is influenced by energy sources such as solar radiation. The Aeronomy Division's principal investigations are in the altitude regions above about 15 km, which include the stratosphere, mesosphere, and thermosphere.

The study of the stratospheric environment is a major activity of the Division. The National Environmental Policy Act of 1969 requires the Air Force to provide environmental impact statements for the operation of aircraft such as the F-16 fleet. Questions which must be answered include: What will aircraft emissions do to the ozone content of the stratosphere? How will this affect the environment on earth, which influences agriculture and marine life? To answer questions such as these, the Division is engaged in a cooperative program with other government agencies such as Army, Navy, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Department of Energy, Environmental Protection Agency, National Science Foundation, and the Department of Transportation. The Division performs stratospheric experiments primarily by using high-altitude balloons to determine trace-gas, ion, and aerosol composition of the stratosphere with special emphasis on those constituents that react chemically with stratospheric ozone.

The solar ultraviolet radiation incident on top of the stratosphere and its absorption within the stratosphere by ozone and other trace constituents are measured by means of spectrometers flown on balloons and rockets. Stratospheric winds, temperature, and turbulence are being measured with balloons and sounding rockets to develop models for predicting the dispersion, spreading, and lifetime of aircraft and missile exhaust products in the stratosphere. The effects of engine emissions and aircraft venting of unburned fuel on the environment are also assessed. Laboratory experiments are conducted to measure parameters and reactions of important stratospheric molecules. Models for waves and turbulence in the stratosphere are developed for determining the environmental effects of Air Force operations.

The measurement of ultraviolet radiation is another major effort in the Division. Ultraviolet radiation from the sun is the principal source of energy for the earth's upper atmosphere and has a dominating influence on atmospheric composition, density, and ionization. Atmospheric background radiation in the ultraviolet region of the spectrum limits the detection capability of ultraviolet surveillance systems. Also, ultraviolet radiation emanating from the earth's horizon has the potential of providing improved horizon sensors for satellite navigation systems. These sources of ultraviolet radiation are measured with optical spectrometers flown on rockets and satellites.

Another major area is the development of improved models of the properties of the earth's upper atmosphere. The Division has had a major role in the development of U.S. Standard Atmosphere, 1976, a cooperative effort involving the Air Force, the National and Space Administration, and the National Oceanic and Atmospheric Administration. In systems operations, the Division is working on atmospheric density models and on geopotential models for the Aerospace Defense Command to be used in its tracking operations of all space objects. The atmos-



Ionospheric structure and composition of the nighttime equatorial E and lower F regions.

pheric data necessary for the development of these models are obtained from mass spectrometers, ionization gauges and accelerometers flown on rockets and satellites. Neutral atmospheric density and temperature are also obtained by falling spheres launched in rockets. A parallel laboratory effort in theoretical density studies, atmospheric modeling, and measurements of ion-neutral reaction rates has improved the understanding of the chemical processes occurring in the upper atmosphere.

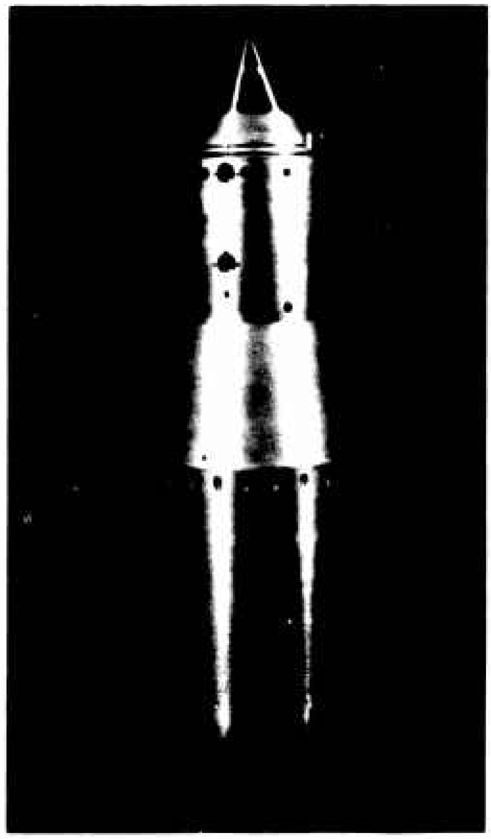
Another major area is the study of disturbed atmospheres. Systems operating in or through the earth's upper atmosphere may be affected by both natural disturbances such as polar cap absorption events, auroral events, and sudden ionospheric disturbances, and by atmospheric nuclear detonations. The Division, in cooperation with the Defense Nuclear Agency, is measuring atmospheric properties during natural disturbances and developing models which are used as inputs to computer codes for predicting the atmospheric effects to be expected from nuclear detonations. Among the properties measured are the ion and neutral composition of the upper atmosphere and equatorial ionospheric irregularities. The studies are accomplished with mass spectrometers flown in sounding rockets to probe the D and E regions of the ionosphere. In addition, laboratory experiments are performed to study chemical reactions that may also occur in the upper atmosphere such as the study of thermochemical properties of metal oxides and reactions between atmospheric ions and molecules.

The Division's investigations are performed by means of theoretical studies, laboratory experiments and experiments by means of aircraft, balloons, sounding rockets and satellites. The satellite experiments are performed both on Air Force satellites and on satellites of the National Aeronautics and Space Administration (NASA). The Division is supporting the Defense Meteorological Satellite Program. The Division has experiments on the NASA Atmosphere Explorer satellites. It recently has had a successful experiment on an Air Force-STP satellite to measure ultraviolet background radiation. Proposals for future experiments for SPACELAB have been submitted. One of these experiments proposed will use a laser beam to probe the earth's atmosphere down to the stratosphere to determine atmospheric densities on a global basis. Two other proposed experiments will measure global background radiation in the ultraviolet and the long-term variations of solar ultraviolet radiation.

STRATOSPHERIC ENVIRONMENT

Interest and concern has been focused on the stratosphere during the last few years because it is becoming evident that man's activities can significantly change the environment. Banning of chlorofluoromethanes in aerosol sprays has been suggested, because they may contribute to the destruction of the ozone layer in the stratosphere. Some Air Force weapons systems operate in the stratosphere, and careful evaluations must be made to avoid inadvertent modification of the environment.

The stratosphere is commonly defined as that part of the lower atmosphere where the



Forward end of D region ion mass spectrometer payload showing the conical sampler. The ambient ions enter through a 0.030 inch diameter hole at the cone's apex.

temperature increases with altitude, typically extending from 12 to 50 km. Ozone is a minor constituent of the stratosphere, but it is directly important to man because it absorbs harmful solar radiation. Although its concentration is only a few parts per million, ozone is the only atmospheric constituent which can absorb solar radiation between 200 and 300 nanometers. The increase of temperature with altitude in the stratosphere creates a very stable region, which does not have any obvious exits for gaseous pollutants. Pollution remains in the stratosphere for years, all the time chemically reacting to reduce the ozone concentration. Thus, even small amounts of pollution can have a large effect on the ozone concentration.

The stratospheric environment program has the important task of predicting what environmental changes can occur from USAF missile and aircraft operations in the stratosphere. In this program, minor stratospheric constituents, aerosols, solar energy deposition, and pollution transport properties and residence times in the stratosphere are measured. These measurements are made with unique, state-of-the-art instruments flown on large balloon systems. Mathematical models are continually revised by incorporation of the newest determinations of reaction rate constants and data on density. A respected scientific technology base and predictive models exist to determine if changes occur in the atmosphere as a result of emissions from USAF flight operations. This capability has been used to provide environmental assessments on aircraft and missile systems.

Whole-Air Sampling Measurements: The primary method for measuring the composition of the stratosphere is to fly a cryogenic vessel on a high-altitude balloon, collect a one-mole sample, and return it to the laboratory for trace gas analysis. Cryogenic sampling provides large sample quantities and minimum potential for chemical changes in the stored sample. The first liquid helium cooled sampler used in this program collected a single one-mole sample on each flight. A newer tri-sampler collects a one-mole sample at each of three altitudes on each flight, providing both more economical operation and same-day measurements of a large altitude range.

Three sample holders are immersed in a single liquid helium chamber which is thermally shielded by both liquid nitrogen and vacuum blankets. The sampling valves are remotely actuated in sequence. The air sample tubes are sized for the altitude at which they are used so that the air molecules enter slowly enough to freeze on their first contact with the cylinder wall. Samples are taken only while the balloon is descending, and a fan downstream from the sampling tube draws air across the sample tube inlet from a larger diameter tube which extends 6 meters below the gondola. These precautions prevent contamination of the samples by the flight package.

The original gondola is approximately spherical, with a flat base and a low center of gravity, so that it is self-righting. A second gondola was designed to be compact, rugged, and aerodynamically stable, for use when air snatch of the package is necessary.

Nine flights, all successful, were conducted during the reporting period. Samples were obtained at five latitudes, and six altitudes: 12, 15, 18, 20, 25, and 30 km. The flights from Alaska and Panama were air snatched, while those from California, New Mexico, and South Dakota were recovered from the ground.

Nitric oxide and nitrogen dioxide concentrations are measured with two chemiluminescence analyzers with different designs measuring different emission wavelengths. In this way, concentrations in the low parts per billion range are measured more accurately and spurious signals from other chemiluminescent reactions are kept to a minimum. Nitric oxide and nitrogen dioxide concentrations measured are higher than those obtained in most other experiments, do not vary markedly with latitude, and exhibit an altitude profile similar to the June 1978 Alaska results.

The other chemical species of interest are analyzed with a gas chromatograph. The present instrument uses a custom injection system, nitrogen carrier gas, and an electron capture detector to achieve stronger and better resolution of early eluting trace gas peaks, permitting measurements down to the low parts per trillion range. Concentrations of nitrous oxide were found to drop off from the troposphere value of 320 parts per billion to approximately 100 parts per billion at 30 km near the equator. The decrease was greater at higher latitudes. Fluorocarbons 11 and 12 were measured in the parts per trillion range and exhibit variations with altitude and latitude similar to that for nitrous oxide.

Any changes with time of any of these concentrations will provide input for possible correlations with increased Air Force operations in the stratosphere.

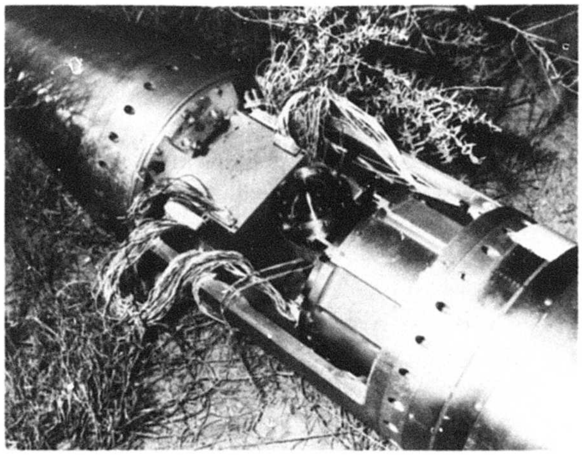
Mass Spectrometer Measurements: To complement whole air sampling measurements, preparations are being made to sample both positive and negative ions in the stratosphere with a balloon-borne quadrupole mass spectrometer. It has been suggested that a balloon gondola could charge to a high potential, adversely affecting the measurement accuracy. To see if this problem is real, the potential to which a balloon gondola charges in the stratosphere was measured.

The charge on the gondola was determined by measuring the potential difference between a small sphere held extended from the gondola and the gondola itself. The sphere has a small radius so that a large electric field would result from a small potential, and thus tend to remain close to the plasma potential. The sphere was platinum plated to reduce photoemission.

The first measurements detected a potential of only a few volts. Further measurements are scheduled.

A switched positive and negative ion mass spectrometer has been developed and is being prepared for measurements starting in 1980. The results will be used to evaluate ion chemistry in the stratosphere and its interaction with pollutants.

Stratospheric Aerosols: Trapping stratospheric aerosols and returning them to the laboratory for analysis is the method which has been used up till now. Howeer, chemical changes, such as the evaporation of volatile constituents, can occur in the time between capture and analysis. A new aerosol composition instrument being developed will avoid this problem by vaporizing the particle with a laser pulse and then identify the vaporized fractions optically. The first flight of this new instrument is planned for 1982.



Recovered DMSP/SSD mass spectrometer payload showing the gas accommodation sphere.

Wave and Turbulence Models: Turbulence is one mechanism by which stratospheric constituents are mixed and pollution transported out of the stratosphere. The contribution of turbulence to pollution transport is now known. However, the extent ofsmixing is an important factor in the determination of the stratospheric chemistry.

During this reporting period, we have studied the assumptions made by other investigators. Measurements of turbulence were made by a U-2 flying in the 20 km height range. When the power spectrum of the wind fluctuations was determined, it seemed to be the "Kolmogorov inertial range spectrum," which is the typical spectrum of turbulence. However, the wavelengths extended to lengths much too long to be turbulence. We found that these spectra can be explained if the long wavelength components are gravity waves due to buoyancy effects. Tests will be performed soon. If they validate this theory, then previous estimates of turbulence transport may have to be completely revised.

Theoretical work on an AFGL-developed turbulent transport model is a second effort in this area. The model has proven useful since it seems to be the only model for vertical stratospheric turbulent transport which uses vertical profiles of the horizontal winds obtained by rocket trial data or by radar data on atmospheric reflections.

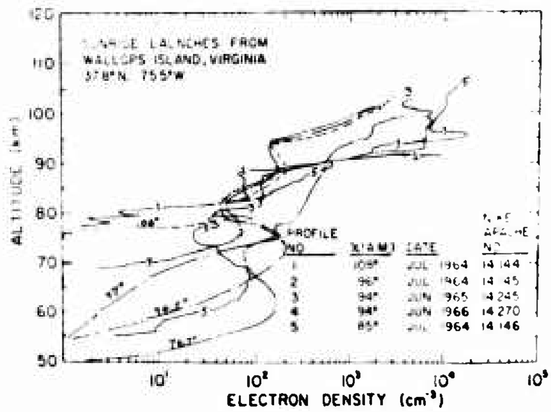
Turbulence Measurements: Several measurement techniques are being used to define the persistence, altitude distribution, latitudinal variation and seasonal variation of stratospheric turbulence. The altitude distribution is measured by analysis of vertical smoke trails deposited by rockets. Time lapse photographs of the smoke trails are analyzed to an altitude resolution of 10 meters. This permits identification of the pancake-like turbulence layers, several hundred meters in thickness. The smoke trails are deposited at twilight by release of a titanium tetrachloride-water-methanol mixture which produces dense chemical smoke from an altitude of about 15 km to rocket apogee. In a series of experiments in 1976-77, the rocket apogee was near 25 km. A more comprehensive program was begun in 1978 in which the apogee was near 55 km. The new program will investigate the variations in stratospheric winds, wind shears and turbulence with latitude. In 1978, two rockets were flown from Wallops Island, Virginia (latitude 38 degrees N) and Fort Churchill, Canada (latitude 58 degrees N). This program will be finished in 1979 with a series of rocket launches scheduled at Lima, Peru. They will provide the data for equatorial latitudes. Measurements of temperature, nearly simultaneous with the rocket launches, will be combined with computed wind shears to determine profiles of Richardson's number as a function of altitude.

A second method of measuring turbulence is to use a turbulence sensor mounted on a balloon. The balloon sensor can float in a turbulence layer for long periods of time to record the lifetime of the turbulence layer. The instrument, developed specifically for stratospheric measurements, senses the deflection of a transverse corona ion beam caused by the wind and turbulence. The velocity and velocity fluctuations are measured and analyzed to obtain altitude profiles of the wind shear and Fourier spectra of the fluctuations to identify the turbulence. A series of flights from Holloman AFB, New Mexico, measured turbulence in the vicinity of mountains. Similar flights from Watertown, South Dakota, measured turbulence over the Great Plains. Analysis of the wind shears and turbulence spectrum determines the eddy diffusion coefficient of the stratosphere with and without mountain effects.

Radar observations of scattering layers at altitudes up to 20 km provide one means of observing turbulence over long periods of time. Data from the Millstone radar were analyzed with simultaneous radiosonde data to provide estimates of the eddy dissipation rate and the eddy heat diffusion coefficient. The median eddy diffusion coefficient between 13 and 16 km altitude did not change from season to season.

Rawinsonde data taken at 144 stations between 1970 and 1976 for altitudes of 0-30 km, and rocketsonde data taken at 10 stations between 1969 and 1975 for altitudes for 20-55 km were acquired on magnetic tape from NOAA. Smooth curves were fitted to the temperature and wind observations, and the Richardson number, a criterion for the onset of turbulence, was obtained at 1 km intervals. Where the Richardson number indicated turbulence, an empirical formula was used to obtain the turbulent intensity, the dissipation of kinetic energy, and the turbulent diffusivity. Levels with pronounced occurrence of turbulence are found in the troposphere. The levels vary with season and latitude. Global models of turbulence as a function of season, latitude, and altitude are being developed for use in the troposphere and stratosphere.

Solar Ultraviolet Measurements: Solar ultraviolet radiations at wavelengths from 200-310 nm were measured at altitudes up to 40 km on four balloon flights. A grating spectrometer with a wavelength resolution of 0.012 nm obtained data of excellent quality on the 8-hour flights. Solar radiation intensities and ozone concentrations are being determined from these measurements.



Sunrise D and lower E region electron densities predicted theoretically compared to measurement by Langmuir probes. The χ angles for the measurements and theory are given in the figure.

Ozone Photodissociation: Relatively little is known about the state of the ozone molecule after it absorbs ultraviolet radiation. The bond strength and geometric structure for the upper electronic state of the molecule are unknown. They are important for understanding ozone destruction processes. An indication of the bond strength is given by the potential well depth. The potential well depth, in turn, can be inferred from the location of the band of absorption caused by the lowest energy transition from the ground state to the upper electronic state. For over 30 years, the band at 351.3 nm was assumed to be this band. However, isotope shift analysis and the observation of previously unreported bands for cooled ozone, show that this transition should give rise to a band at 368.6 nm. This results in a potential well depth for the upper electronic state which is 1328 cm^{-1} deeper than previously assumed. Studies to deduce the geometrical structure are now in progress.

Environmental Assessments of Engine Emissions: The possible damage to the stratospheric ozone was assessed for the F-16 fleet, the KC-10A tanker fleet and the High Altitude High Speed Target. It was found that F-16 and KC-10A operations would have no measurable effect on stratospheric ozone. The computations indicated that the ozone should increase slightly, in line with recent developments in stratospheric chemistry which indicate that an injection of nitrogen dioxide below 25 km will cause an increase in ozone.

Nitrogen dioxide and hydrogen fluoride are the only effluents of concern from the High Altitude, High Speed Target. Because a small number of flights are contemplated, the concentrations of the effluents will be much below ambient. No environmental damage is anticipated from these flights.

Aircraft Venting of Unburned Fuel: Environmentalists are concerned about possible changes in atmospheric composition or damage to crops from the occasional jettison of unburned fuel. In an experimental program, a sampling aircraft flew directly through a fuel dump at selected altitudes to measure fuel drop size and number distributions.

The measurement results of the sampling, fuel dump wake size and hydrocarbon vapor content were analyzed and a multi-component fuel drop model was used to predict the amount of drop vaporization and determine the initial drop size and number distribution. The observed drop size distribution was corrected for evaporation using the model to estimate the initial droplet formation size. For the KC-135 aircraft fuel venting procedures, the median drop diameter formed is 270 μm. It was determined that fuel jettisoned 5,000 feet or higher will evaporate before reaching the ground. Ground contamination can be avoided, eliminating any potential environmental damage.

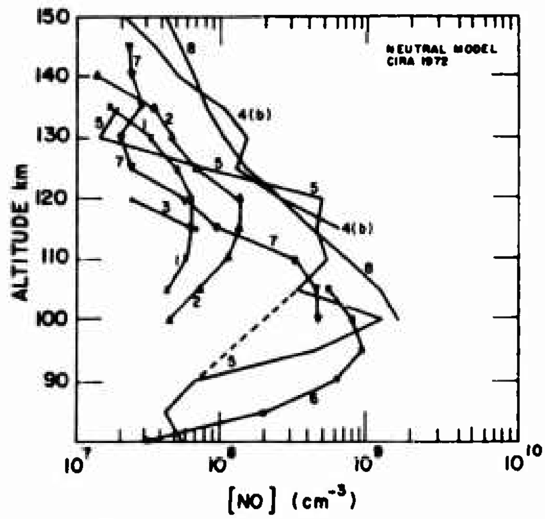
UPPER ATMOSPHERE COMPOSITION

The local detailed chemistry of the upper atmosphere determines the electron distribution in this region. The electron distribution, in turn, affects radio waves, radar, and satellite signals. The Air Force needs to know the chemistry of the normal and disturbed upper atmosphere. It also needs to know the effects of nuclear detonations on the upper atmosphere.

Equatorial Ionospheric Irregularities: The Defense Nulcear Agency conducted rocket and ground-based programs at Kwajalein during Augut 1977 and 1978 to examine radio communications. Rockets, and ionosonde, and radar measured the ionosphere simultaneously, while signals from the DNA WIDE BAND satellite were measured. A Talos-Sergeant-Hydac rocket carrying an ionospheric diagnostic payload was launched near midnight on August 23, 1977, attaining an apogee of 161 km. The AFGL-supplied mass spectrometer obtained excellent measurements between 78 and 161 km. The results showed a sporadic E layer near 109 km composed of meteoric ions with silicon ions dominant, as well as higher altitude layers composed mainly of nitric oxide ions. From this layer structure, wind patterns and motions which may initiate ionospheric instabilities may be deduced.

Two similar rockets were launched from Kwajalein on August 8 and August 13, 1978, both with apogees of about 230 km. Measurements between 100 and 230 km showed that the ionospheric E and lower F regions were typical of quiescent conditions, and consisted of nitric oxide ions, along with about 10 percent oxygen ions. The F-region ledge composed of atomic oxygen ions was apparent near apogee. These results have defined the ionospheric structure near the lower boundary of the F-region instability.

In another effort, quadrupole ion mass spectrometers have been designed and constructed to study ionospheric irregularities from the space shuttle. Plans call for these instruments to be boom-mounted on the shuttle. In the future they will also be included on the Low Altitude Satellite Studies of Ionospheric Irregularities (LASSII) satellite, which will be launched and retrieved by the space shuttle. These efforts are joint agency programs involving principally the Air Force Geophysics Laboratory and the Naval Research Laboratory.



Nitric oxide profiles inferred from analysis of eight ionic composition profiles using the mean CIRA 1972 atmosphere.

D-Region Ion Mass Spectrometer Development: **A new rocketborne mass spectrometer system was designed, built, tested and flown for measurements of positive and negative ions in the D and sub-D regions (from about 35 km up). The instrument consists of a double quadrupole mass spectrometer housed in a liquid helium cryopump. Its unique feature is a conical sampling structure designed to attach and swallow the shock wave in order to avoid thermodynamic breakup of the large positive and negative cluster ions observed in the D region. The spectrometer configuration has undergone extensive wind tunnel**

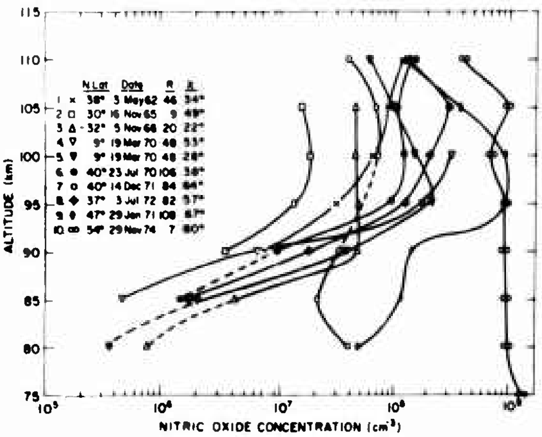
tests to insure that the shock wave is attached. An engineering test payload containing this instrument and two Gerdien Condensers to measure positive and negative ion mobilities and densities was launched on a Nike Tomahawk from White Sands, New Mexico, at 1500 MDT on September 15, 1978. Measurements were obtained between 48 km and apogee, which was at 114 km. A number of instrumental parameters were varied to examine ion sensitivity and mass resolution as well as cluster ion breakup as a function of the ion draw-in electric field. Cluster ions were observed below 82 km giving way to nitric oxide and oxygen ions above this altitude. Meteoric ions of sodium, magnesium, aluminum and iron were also found in a broad layer near 93 km. Breakup of the large cluster ions was observed when the ion draw-in electric field was increased, and instrumental sensitivity and resolution parameters were determined. It is planned to conduct several measurement programs with these instruments, including a total solar eclipse and solar proton events. These measurements are required to develop D-region models for both natural and nuclear disturbances to determine and predict the effects on systems using VLF, LF and HF propagation.

DMSP Supplementary Sensor Density Calibration: A neutral mass spectrometer was designed, built and flown on a rocket to measure composition and density between 120 and 200 km. This instrument will be used in a joint AFGL program to calibrate the supplementary density instrument on board the DMSP satellites for the purpose of obtaining real-time satellite drag. The mass spectrometer uses a spherical gas accommodation sampling geometry. The gas is thermalized in the sphere before being analyzed by a quadrupole mass spectrometer. In this manner, the inside pressure can be related to the ambient accurately.

The payload, after launch, performs a 90-degree yaw maneuver and cartwheels along the trajectory, spinning the mass spectrometer orifice in and out of ram. This is done to determine the rocket outgassing background, which is a significant signal, especially for nitrogen. Nitrogen, argon, helium and oxygen concentrations are measured. This payload was successfully test flown on September 15, 1977 from the White Sands Missile Range, obtaining measurements between 110 and 200 km.

Nitric Oxide: Auroral and Quiet E-Region: A rocket-borne mass spectrometer launched from Poker Flat, Alaska, on March 27, 1973, at about midnight was successful in measuring the ion composition within an auroral arc. Analysis of the data showed good agreement with a model using laboratory rate constants if the nitric oxide concentration was allowed to reach 10^9 cm^{-3} near 105 km, this concentration being about ten times the normal amount expected.

Subsequently, the ion composition profiles of all eight published auroral flights were compared with an auroral ion composition model. Five of these eight flights were by AFGL. Although no clear pattern



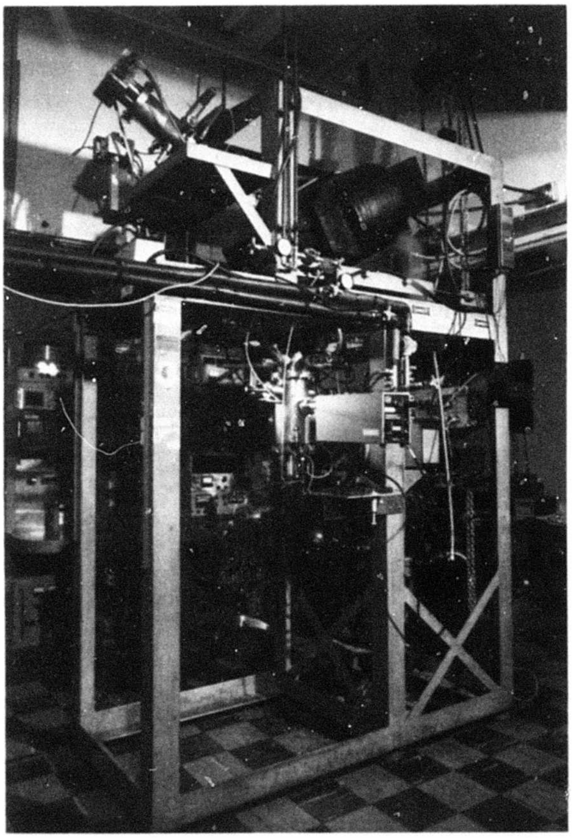
Nitric oxide distributions determined from ion composition experiments for the indicated latitudes, dates, sunspot numbers, and solar zenith angles.

was discernible from the NO^+/O_2^+ ion ratio for the eight flights, comparison of the data with the model showed that the neutral nitric oxide profiles of the auroral E-region ranged from normal to enhancements of an order of magnitude above normal. This deduction is in general agreement with nitric oxide gamma-band satellite information by others. On the other hand, our results essentially refute information by one group which suggested that nitric oxide could attain concentrations at least as large as 10^{11} cm^{-3} in the E region.

Nitric oxide profiles were deduced recently from all ten of the available ion composition data sets available for the non-auroral daytime E-region. Excluding the three high-latitude winter profiles, the nitric oxide profiles obtained are generally in good accord with concentrations determined from gamma-band measurements of nitric oxide radiation. Within a factor of 3, nitric oxide concentrations were found to vary from 1×10^8 cm^{-3} at 100 km to 2×10^6 cm^{-3} at 85 km for various sunspot numbers and seasons, except winter. This strong gradient suggests a vertical eddy diffusion coefficient in the lower range of those thought to be appropriate. The three winter mid-latitude data sets, all associated with anomalous D-region radio absorption, yielded higher NO concentrations, two profiles attaining peak values of 10^9 cm^{-3}.

Disturbed D-Region Modeling: Further progress was made in interpreting the many measurements taken during the November 2-5, 1969 Polar Cap Absorption (PCA) event, or, solar proton event. Absorption data obtained during this event at 36 MHz (ordinary and extraordinary waves), 18 MHz and 9 MHz for four rocket flights plus 30 MHz riometer data were shown to be in good accord with theoretical calculations. More recently, a model for this event was published which agrees quite well with the data except for sunrise conditions. The model does not include hydration processes for negative ions; this exclusion is a principal reason for the model's disagreement with the data at sunrise.

Laboratory Studies: During this reporting period, the assembly and calibration of a high temperature mass spectrometer was completed. This instrument has been used to measure the thermochemical properties of a number of metal oxides which are of interest in understanding the composition of the upper atmosphere. There are four classes of these metals. First, metals which are present in meteorites may form oxides when they enter the earth's atmosphere. Thermochemical data for these species are



High temperature mass spectrometer.

needed to assess their importance in understanding the chemistry of the natural atmosphere. Second, metals are sometimes released in the earth's atmosphere to study specific geophysical phenomena, for example, winds or magnetic fields. The fate of these metals when they react with the atmosphere is determined by the thermochemical properties of their oxidation products, and thermochemical data are needed to evaluate which products are formed. Third, metals are also released into the earth's atmosphere by nuclear bursts in the atmosphere. Some of the fission fragments thus released can undergo reactions with the ambient to form metal oxides, and to evaluate this avenue of reaction, thermochemical data are often useful. Finally, metals are used as fuel additives in jet fuels, so that metals and their oxides are often released in the ambient. Thermochemical data are useful in evaluating the importance of these species as intermediates in maintaining or disturbing the chemical equilibrium in the upper atmosphere. For the above reasons the thermochemical properties of a number of metal oxides were studied: EuO, TiO_2, GdO, NdO, and PrO. Preliminary work has also been done on MgO and MgOH.

In addition to the thermochemical work, a double mass spectrometer which is used to study ion-neutral collisions involving atmospheric species has been modified to study the reactions between atmospheric ions (such as O^+ and N^+) with vibrationally excited atmospheric molecules (such as N_2). This modification consisted of the addition of a beam modulation system and phase-sensitive detection to the apparatus. Preliminary data have been obtained for the reaction of O^+ with vibrationally excited N_2, but the noise levels are at present quite high. Some experiments have also been performed to study the cross section for the reaction of Mg^+ with water. Qualitative first experiments indicate that a reaction occurs.

To understand the composition of the metal-ion layer and how the chemical balance leading to it is maintained, a survey was conducted of the thermochemical and kinetic data available for a number of metallic species which have been reported in the metal-ion layer. This survey has been published as a technical report. One conclusion of this study is that most of the metals will not form metal oxide ions.

SOLAR ULTRAVIOLET RADIATION

Solar ultraviolet (UV) radiation having wavelengths between 50 and 3500 angstroms is completely absorbed by the earth's atmosphere at altitudes above about 15 km. This atmospheric absorption is the major source of heating in the earth's stratosphere, mesosphere, and thermosphere and controls the neutral and charged particle composition and photochemical processes occurring in these regions. Measurements of the spectral distribution, the absolute intensities, and the temporal variability of solar UV radiation are necessary inputs to any study of the photochemistry of the earth's atmosphere. The solar parameters as well as the altitude dependence of the absorption of the solar UV within the earth's atmosphere are required as input data for the development of atmospheric density and ionospheric models. Solar UV absorbed by the atmosphere also provides the energy for production of the atmospheric airglow radiation which surrounds the earth. This is important because if we understand the processes that produce airglow radiation, we may be able to determine atmospheric parameters from satellite measurements of airglow radiation.

Radiometric measurements of solar UV radiation are made with calibrated spectrometers mated with solar pointing controls and carried by rockets and satellites to altitudes well above 100 km. The rocket payloads frequently carry electron spectrometers and photometers to measure atmospheric photoelectron fluxes and UV airglow radiation.

Rocket Measurements of Solar UV: The optical entrance apertures of the rocket-borne spectrometers are pointed at the center of the solar disk during data acquisition. The flux emitted from the entire solar disk is measured, since the full disk flux is the important parameter for atmospheric studies. Photomultiplier detectors operated as photon counters record the solar intensities, and the data are telemetered to ground receiving stations.

During this reporting period, several rocket experiments measured solar UV in the 1250 to 3500 angstrom range. Radiation in this wavelength region is particularly important to the stratosphere and mesosphere. The absorption of solar UV between 1300 and 2000 angstroms in the Schumann-Runge continuum and bands dissociates O_2. This dissociation is an important energy source between 80 and 120 km and is the source of atomic oxygen throughout the thermosphere. The solar flux between 2000 and 3500 angstroms is absorbed predominantly in the stratosphere and mesosphere between about 15 and 80 km by O_2 and by other minor constituents such as ozone. This absorption controls the ozone balance in the stratosphere and many other photochemical reactions. On April 21, 1977 the first successful coordinated measurement by a rocket spectrometer and balloon-borne spectrometer was carried out. Both spectrometers were Ebert-Fastie configurations and measured absolute fluxes in the wavelength region 1750 to 3500 angstroms with a spectral resolution of 0.1 angstrom. The rocket spectrometer measured absolute solar fluxes incident on top of the stratosphere, while the balloon spectrometer measured solar flux within the stratosphere where the flux is absorbed. These data, obtained simultaneously, will be used to study stratospheric photochemistry and to develop stratospheric models.

A newly designed double Ebert-Fastie spectrometer flown in a rocket on August 9, 1977 has provided data on solar UV fluxes in the extended wavelength region 1250 to 3500 angstroms with a spectral resolution of 0 1 angstrom. This instrument was again flown successfully on September 19, 1978. The data obtained from these two rocket experiments will provide an excellent data base on solar fluxes in the wavelength region of importance to the stratosphere and mesosphere.

A promising method of obtaining atmospheric densities remotely from a satellite consists of measuring the intensities of atmospheric emission of the molecular nitrogen second positive band at 3371 angstroms and the atomic oxygen intercombination line at 1356 angstroms. These airglow emissions measured at the satellite, when deconvoluted, can be used to infer the atmospheric densities of molecular nitrogen and atomic oxygen. Future DMSP satellites will contain airglow photometers to make these measurements. To verify the remote sensing capability of the DMSP satellite, a rocket payload has been instrumented and will be flown in 1979 in coordination with overhead passes of the DMSP satellite. The rocket experiment will obtain *in situ* measurements of solar UV intensities, neutral particle densities, photoelectron energy distributions, and molecular nitrogen and atomic oxygen airglow radiation at 3371 and 1356 angstroms, respectively. The *in situ* rocket measurements will allow the interrelated atmospheric processes and parameters leading to airglow radiation to be measured and applied to the verification of the DMSP density measurements. Data on the atmospheric photoelectron fluxes obtained previously in a test flight of this rocket payload have now been analyzed and published. The photoelectron fluxes were obtained with a 127-degree cylindrical electrostatic deflection analyzer consisting of entrance and exit slit aperture assemblies, deflection plates, and a channeltron detector operated as an electron counter. Energy scanning is accomplished by varying the differential voltage applied to the deflection plates. One complete energy scan is obtained in 1.3 seconds; therefore, the photoelectron energy distribution can be obtained as a function of altitude in the earth's atmosphere. The data obtained from the test flight of the electron spectrometer have provided the first measurements of the relative values of thermospheric photoelectron fluxes with high energy and altitude resolution.

Satellite Measurements of Solar UV: Satellite-borne instrumentation affords the opportunity for nearly continuous solar flux measurements over extended time periods. Such measurements allow one to determine temporal variations of solar UV that occur during the 27-day solar rotation and during the 11-year solar cycle. There is active controversy concerning the variations of solar UV during the 11-year cycle, primarily because no systematic program to measure these fluxes with high accuracy and extended wavelength coverage during a complete cycle has ever been carried out. The UV spectrometers, designed and supplied by AFGL as part of the three payloads of the NASA Atmosphere Explorer (AE) series satellites, have provided the most significant information to date on the variations of solar UV with solar activity. AE-C was launched during December 1973, and AE-D and AE-E were launched during October and November 1975. The operational lifetimes of both AE-C and AE-E have exceeded their design lifetimes by several years. Although AE-C is no longer operating, AE-E is expected to operate well into 1980. These AFGL spectrometers, therefore, will have provided data on solar UV for a period of about seven years.

Several significant results on the variation of solar UV radiation with solar activity obtained from the AFGL spectrometers have been published. A particularly important result obtained from the AE-C spectrometer is that the minimum value of solar UV fluxes occurred about 14 months earlier than the minimum sunspot number of July 1976. This discovery of a major phase difference between the solar UV flux minimum and solar sunspot cycle minimum can have a major impact on the development of atmospheric and ionospheric models. Existing models are based on the assumption that solar UV fluxes, which are the major source of energy input in the upper atmosphere, are in phase with the sunspot number and the related 10.7 cm solar radio emission. Another important result is the unexpected rapid increase in solar UV flux during the development of the new solar cycle which began in July 1976. The increase in flux appears to be well correlated with the increase in the 10.7 cm solar radio emission, in sharp contrast to observations made during the previous solar cycle when the correlation between solar UV and 10.7 cm emission was poor.

ATMOSPHERIC ULTRAVIOLET RADIATION

The emission from the atmosphere in the wavelength region 1100-4000 angstroms can be observed from space, and offers the possibility for several applications. These include detection and surveillance of mis-

The vacuum ultraviolet radiation background presented by the earth, as measured from a satellite. Experiment CRL-246 measured global VUV radiation levels, with emphasis on the levels between the bright atmospheric emission bands. It also measured the local variability and enhancement, typified by the auroral emissions at high latitudes and the crossed equatorial bands.

siles based on their UV exhaust plume intensity, remote sensing of atmospheric conditions such as electron density and species concentrations, and development of improved earth horizon sensors based on the distinctive UV limb profile.

Missile Exhaust Plumes: As part of AFGL's Multispectral Measurements Program (MSMP), the UV radiation emitted by missile exhaust plumes is measured. In this program, spatial and spectral data on small operational bus engines are obtained using an Aries rocket which carries the target engine and a multispectral sensor module. At altitude, the two are separated and a series of observations of the target are made. For this work, it was necessary to develop two types of new digicon imaging detectors for the UV. These were successfully completed and flown on the first MSMP launch. Several additional launches are planned to find the effects of solar illumination, thrust level, and target velocity.

UV Backgrounds: In addition to missile exhaust plume measurements, atmospheric UV background intensities are needed to develop surveillance and tracking systems. The properties of the background are required to predict the signal-to-noise ratio and wavelength bands to be used. The major accomplishment in this area has been the success of the satellite experiment, VUV Backgrounds. This experiment was launched in March 1978 as part of SAMSO's Space Test Program flight S77–2, and it has returned excellent data on the spatial and spectral characteristics of the earth's atmosphere as viewed from space. The wavelength range of 1100 to 2900 angstroms was covered with a dual Ebert-Fastie spectrometer, and spatial structure to 1 km was obtained along the ground track for four VUV filter bands. In addition to measuring the long-term stability, intensity, and variability of the earth's radiance, new observations were made of the UV aurora and the tropical UV airglow.

UV Horizon Sensor: The design of a shuttle experiment, designated AFGL-801, Horizon Ultraviolet Program, has been initiated. This experiment will obtain the earth limb radiance profiles to allow design of more accurate spacecraft horizon sensors. The basic concepts and instrumentation come out of the experience on CRL-246. In addition, the new results available will enable sensitivities of the instruments to be set more exactly.

The flight instruments for the CRL-246 experiment.

UV Missile Warning Receivers: An important step in the flight programs described has been the development of a calibration facility to enable test and radiometric calibration at AFGL. This effort has led to participation in an important triservices program to develop UV missile warning receivers for low-flying aircraft and helicopters. Previously, there has been difficulty establishing standard UV calibrations sufficiently reliable for flight tests, ground chamber tests, and various types of sensors. Our measurements of these receivers help to place laboratory and flight observations on a common basis.

NEUTRAL ATMOSPHERIC DENSITY AND STRUCTURE

Measurements of the neutral atmospheric mass density, temperature, species densities, winds, turbulence, and other parameters have provided a general knowledge of the properties of the mesosphere and thermosphere. These measurements, obtained by rocket and satellite experiments, have provided the basic data for formulating empirical static models, such as the U.S. Standard Atmosphere 1976, and for testing current theoretical and dynamic models of the upper atmosphere. Understanding some of the properties has raised other questions of importance. For example, atmospheric tidal components and amplitudes must be described and included in models, and the sources and amplitudes of propagating waves in the upper atmosphere are just now being given serious attention. Dynamic models must not only include the time variation of the mass density and temperature but also accurately model the variation of individual species.

Other major concerns are the spatial and temporal variations of eddy diffusion and the height of the turbopause. These affect the composition of the mesosphere and thermosphere, the distribution of excited states of mesospheric and thermospheric species, the densities of minor species in the mesosphere and thermosphere, and the variations of E- and F-region ion species. Several recently developed techniques have begun to help in answering these questions.

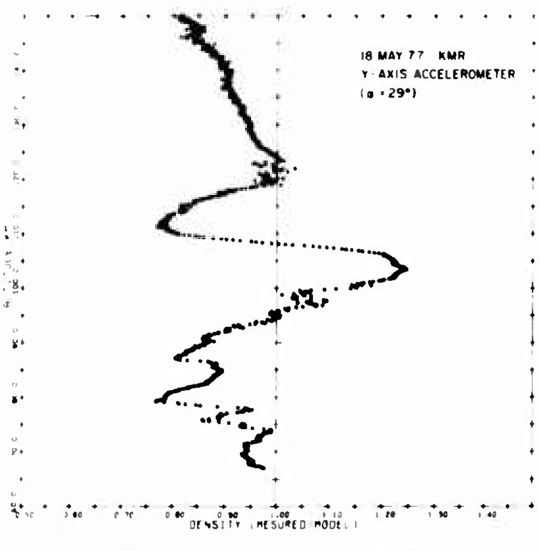
Rocketborne Accelerometer Density Measurements: From 1976 to 1978, the Atmospheric Structure Branch supported three Air Force programs sponsored by the ABRES Program Office of SAMSO. The reentry studies being conducted by ABRES required accurate knowledge of the atmospheric density along the reentry corridor for their tests. In August 1976, a Density Measurements Program was conducted at Kwajalein Missile Range (KMR). The best available techniques were used to obtain a set of measurements. The results were used to determine the variability of the atmosphere in time and space. Error estimates for each of the techniques were reviewed and the techniques were compared. The instruments used included the rawinsonde, rocketsonde, Jim sphere, Robin sphere, and AFGL's accelerometer sphere. This program showed that the atmosphere was sufficiently variable above 60 km to require careful planning where accurate knowledge of the atmosphere is needed. Gravity waves and turbulent layers were found to cause significant differences in mesospheric densities when periods of more than an hour and distances of a hundred or more kilometers were considered. This study at KMR provided radar tracking data of considerably better accuracy than any previous measurements and thus required less smoothing than usual for analysis of the Robin data. The small scale wave structure of the mesosphere could now be seen in the Robin density results. The accelerometer results were obtained using the recently developed PZL Densitometer. This piezoelectric accelerometer is the only technique available that provides high resolution (approximately 100 meters) measurements accurate to 5 percent in the mesosphere and lower thermosphere (the region between 50 and 150 km). All of the techniques agreed well in the regions of overlap. For the first time, the atmospheric density and temperature could be well defined from 0 to 150 km using a rawinsonde (0-30 km), rocketsonde (25-60 km), Robin sphere (40-90 km) and the AFGL accelerometer sphere (50-150 km). In addition, some information on the scale and amplitude of gravity waves, the space variability and time variability were obtained.

The second Density Measurements Program at KMR was conducted in conjunction with the Technology Development Vehicle Program in May 1977. A reference atmosphere for the reentry corridor could be constructed using the results obtained with the various techniques to determine the mean atmospheric properties.

In April 1978, a third program was conducted at KMR in support of the Thrusted Replica Program. AFGL scientists gathered all of the data from the various techniques and developed a reference profile for the atmospheric properties. Confidence limits were placed on each profile based on the errors associated with each measurement and on the spatial and temporal separation.

These studies have now provided the most complete set of atmospheric properties available at one location. Using these results, the wavelengths and amplitudes of gravity waves can be studied and the variability of the atmosphere in turbulent layers can be shown.

The PZL Densitometer experiment used in these measurement programs is a three axis piezoelectric accelerometer. The instrument consists of three proof masses suspended on sensitive piezoelectric crystals so that their center of mass is located at the center of a sphere 25 centimeters in diameter. The sphere contains all of the experiment support hardware, a telemetry system and a radar beacon transponder. The piezoelectric crystals produce a voltage when the crystal is strained by the atmospheric drag acceleration force. The high sensitivity of the instrument allows measurements to be made to altitudes above 150 km. The high space and time resolution of the instrument means that small scale structure can be measured with a resolution of about 100 meters.



Mass density measurements from the PZL Densitometer experiment are shown as a ratio to the USSAS '66 15 degrees N annual model. Each point represents an individual measurement of the density. The wave structure in the profile is partly due to gravity waves propagating through the mesosphere.

The recent measurements at KMR are now being combined into a new KMR Reference Atmosphere. The new model is being prepared by scientists from the Aeronomy and Meteorology Divisions of AFGL with input from a committee made up of scientists from several DOD agencies and contractors. The new model is being prepared at the request of Army and Air Force offices concerned with programs at Kwajalein Missile Range. The model will serve as a basis for mission planning and will be used as a standard for comparison of future measurement programs.

Satellite Accelerometer Density Measurements: An extensive atmospheric density data base has been developed using accelerometer results from four low altitude satellites. The data were obtained with the NASA Atmosphere Explorer (AE)-C, -D, -E Satellites and the Air Force S3-1 satellite. Measurements made on more than 6000 orbits during the period January 1974 to November 1976 were utilized. The altitude range of this data base is from 250 km down to as low as 140 km. Latitude coverage is from 90 degrees N to 90 degrees S and local time coverage includes several 24 hour cycles. Data were obtained over a wide range of geomagnetic conditions. Solar flux was generally quite low during the period of measurement. The data were compared to current atmospheric models to determine the magnitude of unmodeled density variations. This analysis showed that the accelerometer data will permit significant improvement in our understanding of the variations in lower thermospheric density. An empirical model is being developed to describe the accelerometer data in terms of variations with geomagnetic activity, solar flux, latitude, local time and the semiannual effect. This work is an extension of the model developed using only AE-C data as described for the previous reporting period.

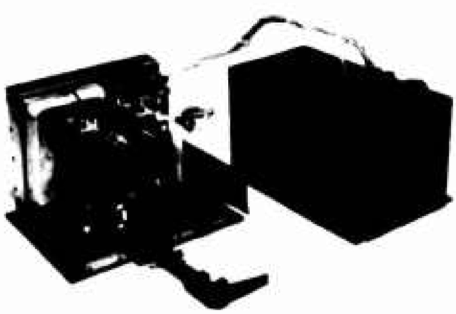
A statistical analysis of the density response to geomagnetic activity observed with the AE-C data was made. This study showed that the commonly used Jacchia 1971 atmospheric model, based primarily on satellite orbital decay data, underestimates the variation in lower thermosphere densities related to geomagnetic activity. Also, the data showed that the thermospheric response during large geomagnetic storms was greater at higher geomagnetic latitudes. For small and medium storms no significant variation of the response was found with geomagnetic latitude. This study is being extended, using the entire data base, to develop a more accurate description of the geomagnetic activity effect as a function of latitude and local time.

The AE-E data were analyzed to determine near-equatorial diurnal and semidiurnal tidal variations in the lower thermosphere. Results showed that the local time density structure changes from predominantly semidiurnal below 180 ± 5 km to predominantly diurnal above this transition height. A seasonal difference in the phase structure of the semidiurnal density component was observed. Also, the phase of the diurnal variation shifted to earlier times with decreasing altitudes. The Jacchia 1971 model incorporates a constant phase as a function of altitude for the diurnal variation, and does not incorporate density variations with a semidiurnal component. The total data base is being studied to extend the tidal analysis to all latitudes.

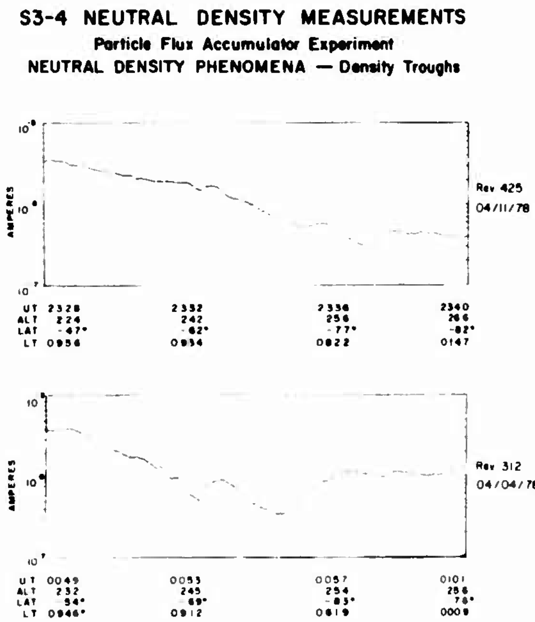
A new single proof-mass triaxial accelerometer was developed. This instrument reduces by about a factor of three the power, weight, size and cost requirements previously encountered by flying three orthogonal single axis units. A total of six instruments were fabricated for flight in conjunction with the Defense Mapping Agency NAVPAC Program. Objectives of the accelerometer are to improve satellite ephemeris determination, to provide density data for use in atmospheric modeling, and to improve gravity field models. The first instrument was launched in June 1977. All three axes provided acceleration data. However, the axis aligned with the drag vector showed an anomalous response to temperature. This precluded obtaining high accuracy density data. The second instrument, modified to reduce thermal response, was launched early in 1978. Data were obtained over a six month period and are currently being reduced.

Analysis of AE elliptical orbit data showed that the accelerometer bias exhibited a temperature dependence. For density measurements on non-spinning satellites in low, near-circular orbits there is no way to determine the bias. ROCA (ROtating Calibration Accelerometer) was designed to provide accurate density measurement by routinely determining bias. ROCA was sensitive along a single axis which could be rotated by 90 degrees. When aligned perpendicular to the velocity vector, the bias was measured. ROCA was flown as part of the S3-4 satellite. S3-4 was launched into a near polar orbit, with perigee near 170 km, in March 1978. The instrument performed as expected and data are being reduced.

Satellite Ionization Gauge Density Measurements: Data obtained from the S3-1 satellite have been completely reduced and processed into neutral density results. These measurements have been edited further to remove noise and compiled into a data base which can be processed by a computer for use in atmospheric structure studies and analysis. Measurements from the S3-2 satellite flight are currently undergoing the same processing procedures and being compiled in the same manner as were the S3-1 ionization gauge measurements. A data base which includes measurements from over 3000 orbits, will be generated as a final product from the two flights. The theory and techniques employed have been documented and published along with representative data samples. Current analysis of the S3-1 data measurements have indicated hemispherical asymmetry in the response of the atmosphere to geomagnetic disturbances. Atmospheric density in the southern hemisphere shows a greater enhancement than the northern hemisphere.



The PFA flight unit.



Atmospheric Trough Phenomena observed from the Air Force S3-4 satellite.

The Air Force S3-4 satellite was launched during March 1978. Two density measuring payloads were designed and constructed for use on this satellite. The newly developed payloads were designated the S737 Particle Flux Accumulator (PFA) units because, in addition to measuring atmospheric neutral density, the units could operate in a secondary mode to measure the satellite's attitude (attack angle). Also, under the proper conditions, the PFA's secondary mode could be used to determine neutral gas temperatures and detect atmospheric winds. The S3-4 satellite was launched into a near circular polar orbit with a perigee of 163 km and an apogee of 263 km. The orbit inclination was 96.3 degrees. Neutral density was measured during a six month period with over 1000 orbits of data being acquired. One of the most interesting effects observed was a persistent trough seen primarily over the southern polar cap region and almost exclusively confined to early morning hours. Measurements of the trough show distances varying from 800 to 4000 kilometers along the satellite path. Similar troughs were observed in the S3-1 data but were seen only infrequently.

The secondary mode operation of the PFA unit was also flight tested in the six month period. The attitude angle of the payload was measured within 1 degree of its alignment position.

THEORETICAL DENSITY STUDIES

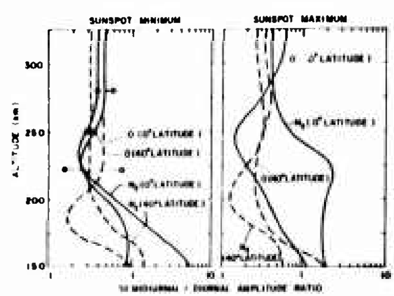
Satellite orbital studies have been primarily aimed at deriving atmospheric densities from orbital decay, and developing and evaluating density models for use in predicting satellite ephemerides. Drag analyses using Doppler Beacon data from three low-altitude satellites (DB-7, DB-8, and DB-9) were compared with results from ADCOM radar skintrack and Satellite Control Facility (SCF) Space-Ground Link Subsystem observations for the same satellites.

The major results were: (1) Predicted positions computed solely from skintrack or SCF data contain relatively large errors due to inaccuracy in the calculated orbital elements. These errors are minimal for the Doppler Beacon data, thus allowing a much improved estimate of the errors due to atmospheric drag. (2) The high accuracy of the Doppler Beacon data permits shorter-term fit spans over which the drag can be determined, allowing study of higher-frequency density fluctuations. (3) Skintrack data yield equally good accuracy for longer-term density variations. (4) Ephemeris prediction errors for low-perigee satellites will increase significantly during the next two or three years due to the increase in solar activity.

The accuracy of six thermospheric models (U.S. Standard Atmospheres 1962 and 1976, DENSEL, MSIS, and Jacchia 1971 and 1977) were evaluated by statistical comparison with data from the Miniature Electrostatic Accelerometer (MESA) and Open Source Spectrometer (OSS) experiments aboard the Atmosphere Explorer-C satellite. The altitude range was 160-200 km, and over 3400 measurements of total mass density from the MESA experiment and 1700 measurements of O, N_2 and Ar number densities from the OSS experiment were considered. The ratio R between the measured density and the model density was analyzed statistically. Frequency distribution plots of R, and tables containing the mean value of R and its standard deviation were constructed for different levels of magnetic activity and compared between the models. Even the most recent models indicated standard deviations of over 15 percent for total mass density and 20-30 percent for O and N_2. This indicates a need for continued *in situ* measurements in the upper atmosphere and a new generation of models in which variations in O, O_2, N_2 and He are considered in conjunction with thermospheric circulation systems.

The Jacchia 1977 and MSIS density models were compared with several older models for accuracy and efficiency in predicting satellite ephemerides for satellites with perigee altitudes ranging from near 170 km to 800 km. While both models compared favorably in accuracy with the Jacchia 1964 and 1971 models, the Jacchia 1977 model required more computer processing time than the older models because of the number of table look-ups, and the MSIS model required more computer time because it contains complicated functions. A simple analytic version of the Jacchia 1977 model similar to the Jacchia-Walker-Bruce model is being developed.

Work has continued on the theoretical modeling of tidal variations in thermospheric composition and total mass density. A formalism including photochemistry, ion chemistry, thermal diffusion, exospheric transport, and specified winds and temperatures was used to develop a model of tidal variations in composition and density. Diurnal and semi-diurnal changes in O, O_2, N_2, Ar, He and H at minimum and maximum levels of sunspot activity were obtained. Sunspot minimum calculations showed excellent agreement with equatorial measurements of O and N_2, both in amplitude and phase for diurnal and semi-diurnal variations between 220 and 280 km. The major exceptions were the equatorial diurnal amplitude of Ar, which the model overestimated by 35 percent, and the



Theoretically computed ratios of semidiurnal to diurnal amplitudes of O and N_2 at 0 degrees latitude (solid curves) and 40 degree latitude (dashed curves) for (left) SSMIN and (right) SSMAX. Results from the San Marco 3 NACE experiment are designated by open circles for O and solid circles for N_2.

equatorial diurnal amplitude of He, which the model underestimated by about 25 percent. Computations for sunspot maximum conditions demonstrated substantial solar cycle differences in the vertical profiles of amplitude and phase for each constituent and in the relative contribution of semidiurnal and diurnal components at different latitudes and heights. Consequently, continued satellite mass spectrometer and accelerometer measurements over different levels of solar activity are needed for the development of comprehensive empirical models of thermosphere tides.

Recent mesospheric and lower thermospheric data and models were reviewed. Data for these regions of the atmosphere were provided by measurements with instrumented rockets and satellites and ground-based detectors, including photometers, partial reflection and incoherent backscatter radars. The quantities and types of data for the lower thermosphere have expanded dramatically during the past few years, primarily due to increased data from incoherent backscatter radars and low altitude satellites. Major emphasis in the review was placed on the development of tidal models and of systematic variations with season and latitude of turbulence intensity and turbopause altitude. Joule and particle precipitation heating rates have been derived from Chatanika incoherent scatter data. Recent models of excitation and propagation of gravity waves and global circulation patterns during magnetic storms were reviewed and compared with satellite data.

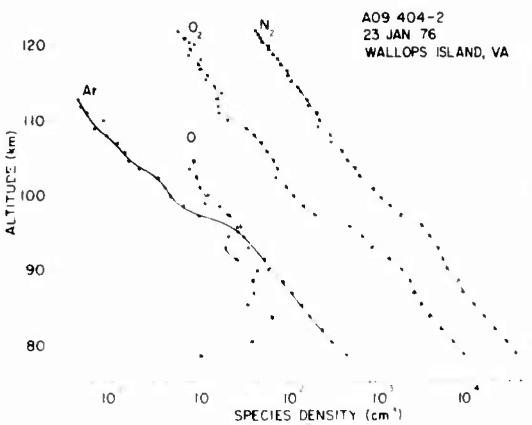
In a review paper on recent atmospheric models, Dr. Jacchia (Smithsonian Astrophysical Observatory) described the OGO-6 model (1974) based on data collekted within a limited range of height and solar activity (solar maximum) as a first step toward a new generation of models. The ESRO-4 model (1977), based on data recorded at lower heights and lower solar activity, was similar in scope to the OGO-6. The Jacchia 1977 model, based on a synthesis of temperature, mass-spectrometer and total density data, was compared to the MSIS model (1977), based on incoherent-scatter temperatures and mass-spectrometer data from various sources.

GEOPOTENTIAL MODEL STUDIES

Two methods were developed for reducing the number of tesseral and sectoral terms in large geopotential models for use with a particular satellite orbit. One method, optimization, selected only those terms whose individual perturbation amplitudes exceeded a specific tolerance. The other method, abbreviation, discarded terms whose total contribution to the ephemeris prediction error at a specified time was less than a specified value. The ephemeris prediction accuracy obtained with these reduced models compared favorably with that obtained with the full model, while saving up to 50 percent of the computer time.

WINTER MESOSPHERE MEASUREMENTS

Several interesting new results were obtained from rocket measurements made in January 1976. NASA, Air Force, and university scientists planned a coordinated rocket program to study the properties of the midlatitude Winter Anomaly. Because of problems with payloads and with severe weather, the measurements could not be made on an anomalous day. However, measurements were made on a normal day for a planned comparison. Rocket payloads containing a liquid helium cryosorption pumped mass spectrometer and a chemical smoke trail were launched by AFGL scientists from Wallops Island, Virginia, on 23 January 1976. The day would be classified as a normal winter day based on the absorption and partial reflection data used to characterize the D-region. This day immediately followed a disturbed period, however.



Density profiles of the major atmospheric species measured at Wallops Island, Va., on January 23, 1976. The measurements were obtained using a mass spectrometer with a liquid helium cryopump.

The results from the mass spectrometer were considerably different from any measurements previously obtained. Four particular features distinguished these data. First, the Ar/N_2 separation from ground level mixing ratio occurred at a very low altitude, near 93 km. Second, the atomic oxygen exhibited the highest peak density observed with this instrument, about 6×10^{11} atoms/cm^3. Third, the altitude of the peak in the atomic oxygen density was low, near 84 km. Fourth, a rather strong wave structure was observed in the altitude profiles of the species. All of these features would be consistent with a period of low eddy diffusion rates based on the theoretical models developed by AFGL scientists. The low altitude separation of argon (40 amu) from the mixed atmosphere ratio is a sure indication of low turbulent diffusion coefficients in the region near 90 km. The high density of atomic oxygen with a peak at low altitude indicates a reduced rate of diffusion to lower altitudes where atomic oxygen is lost by three-body recombination. The wave structure may well be associated with propagating gravity waves which are less likely to be dissipated in the mesosphere if turbulent layers are absent.

The winds were measured using a titanium tetrachloride and water release to provide a smoke trail which was photographed to determine the structure in the mesosphere. The wind structure was accurately determined between 50 and 90 km with a resolution of the small scale structure to about 50 meters. Within the same hour, a third rocket was launched to release a Robin sphere experiment of the Army Atmospheric Sciences Laboratory. The passive sphere was tracked by radar to provide density, temperature and wind results. The wind measurements from the passive sphere agreed well with the chemical trail up to about 70 km and then started to diverge. This is not unexpected because of the smoothing required for the radar data and, possibly, the variation with time of the winds. The temperature results from the sphere were used, together with the wind data, to calculate the Richardson number. A Richardson number of less than ¼ is a good indicator of the presence of turbulence in the region. The turbulent analysis shows that a significant fraction (approximately 30 percent) of the altitude region from 50 to 65 km was turbulent. The region above 65 km appeared to be very stable, even though there were large wind speeds (approximately 80 m/sec) present. This study would indicate a lower degree of turbulence than normal in the mesosphere.

The results from the mass spectrometer and from the turbulence analysis provide a consistent characterization of the conditions of a very stable mesosphere. The question that still remains is whether to associate this condition with the normal winter mesosphere or with the recovery phase following a disturbed period.

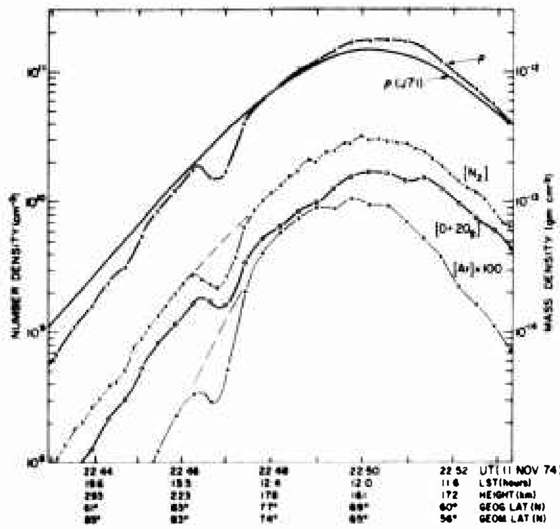
Rocket Measurements of Thermospheric Species: A mass spectrometer has been developed to measure densities of the primary neutral species in the 120 to 200 km region accurately. The instrument will also be used to determine the gas kinetic temperature from measurements of the velocity distribution of nitrogen molecules.

A first test flight of the instrument on 24 September 1977 was degraded by the gas release from the Attitude Control System nozzles. A second flight is planned in 1979 as part of a coordinated measurement program, with care taken to minimize the effects of the Attitude Control System gas release.

SATELLITE MEASUREMENTS OF COMPOSITION

Neutral Species Densities: The mass spectrometer measurements from the S3-1 and S3-2 satellites of the densities of atomic oxygen (O), molecular nitrogen (N_2), argon (Ar) and atomic nitrogen (N) have helped to answer questions about the thermosphere. The large changes (greater than a factor of 10) in argon density in the 160 km and above region at high latitudes have shown that there must be large changes in atmospheric properties in these regions during geomagnetic storm periods. Changes must occur in the temperature profile and in the lower boundary (i.e. the turbopause level) and a convective flow or upwelling of heated atmospheric gases may also occur. Some of the S3-1 results were considered in deducing the geomagnetic effects in the Jacchia 1977 atmospheric model.

The low altitude satellite results from S3-1 have also produced the first identification of the momentum source which was postulated theoretically about ten years ago. The momentum source effect is an in-phase response of all of the constituents. It results from localized pressure gradients which are set up due to momentun transfer from the ionized species moving under the influence of an electric field. Momentum source effects have been observed in about 30 orbits and occur in most cases when K_p is greater than 4 and when measurements were obtained at latitudes above 70 degrees for altitudes between 160 and 200 km. The density departure from a smooth latitude variation can be as large as 40 percent over a few degrees in latitude.



Density profiles of the atmospheric species densities and mass density measured by the MSI spectrometer on the S3-1 satellite. This orbit shows the effect of a momentum source acting on the netural atmosphere, characterized by the density trough near 200 km.

Ion Species Densities: The mass spectrometer experiments on the S3-1 and S3-2 satellites have provided an excellent data base to study the properties of the F-region of the ionosphere. The effects of geomagnetic storms on the high latitude ion densities are striking. During these periods, the normal F_2 peak is at times completely removed by the loss processes due to storm changes in the neutral species and consequent changes in the chemistry. The molecular ions NO^+ and O_2^+ can become the dominant ion species to altitudes of 400 km. The electric fields in the polar cap region frequently cause such irregular structure, with changes in density of a factor of 100 to 1000 in tens of kilometers, that it can be difficult to sort out the various features. Some of the properties of traveling ionospheric disturbances and scintillations can also be studied from the data. Efforts have begun to prepare an ionospheric F-region empirical model based on the data set.

LABORATORY MEASUREMENTS OF ION REACTION KINETICS

Photodissociation and collisional dissociation are two of several types of reactions which molecular ions may undergo in the atmosphere. Laboratory studies provide data on the cross sections and mechanisms of these reactions. Such data are required for the computer models used to predict the effects of natural and nuclear perturbations on atmospheric composition and density. In addition, the laboratory studies provide fundamental information on ion structures, bond dissociation energies, and spectroscopic energy levels. These ion dissociation reactions are studied using double mass spectrometer systems in which a mass analyzed beam of the desired ion species collides either with photons or with neutral molecules, and the ionic products of the reaction are mass and velocity analyzed. In the case of ion photodissociation, the photons are produced by a dye laser tunable in the wavelength range from 260 to 700 nm, with a bandwidth of about 0.1 nm.

Cluster ions are among the dominant ion species in the lower mesosphere and upper stratosphere. The hydrated oxonium ions $H_3O^+.H_2O$ and $H_3O^+.2H_2O$ are of particular interest. Recent work in the Aeronomy Division has shown that, despite their rather weak chemical bonds, these species are surprisingly stable to photodissociation. In this work, upper limits to the photodissociation cross sections for $H_3O^+.H_2O$ and $H_3O^+.2H_2O$ were measured for wavelengths between 265 and 529 nm. Similarly, the hydrated negative hydroxyl ion, $OH^-.H_2O$, for which dissociation to OH^- + H_2O requires an energy input of only 1.08 eV, was found to be stable to photodissociation at several wavelengths between 504 and 650 nm, and only upper limits to the cross sections could be determined.

In other work on ion photodissociation, absolute cross sections were measured for the photodissociation of vibrationally excited Ar_2^+ formed by associative ionization. The tunable dye laser was found to be a useful probe of the vibrational distribution of these dimer ions.

In studies of the photodissociation of the nitrogen oxides, it was determined that excited nitrogen atoms $N(^2D)$ are produced in the photolysis of N_2O^+. No photodissociation of NO_2 could be observed, and upper limits for the cross sections were measured.

Research on collision induced dissociation reactions included studies on CO_3^-, NO_3^-, $OH^-.HNO_3$, $OH^-.H_2O$, and $OH^-.2H_2O$. Cross sections were measured for reactions of these ions with argon, nitrogen, and oxygen in the range of interaction energies from 0.2 to 10 eV, and bond dissociation energies were determined. As a result of this work, ionic isomers were identified for some of the species studied. The existence of such structural variants is important to the subsequent chemistry involving these species. Cross sections were also measured for several "switching" reactions of the cluster ions. Examples are the reactions of $OH^-.H_2O$ with CO_2, SO_2, and NO_2, in which the neutral reactant replaces the H_2O in the cluster ion, producing the more stable ions $OH^-.CO_2$, $OH^-.SO_2$, and $OH^-.NO_2$, respectively. The first two of these are the bicarbonate ion and the bisulfite ion, both well known in solution chemistry.

These switching reactions are very fast over a wide range of interaction energies and represent a major sink for hydrated hydroxyl ions in the atmosphere.

CHEMICAL-TRANSPORT MODELS

The coupling of mean mass motions and other transport mechanisms to chemical production and loss processes demonstrate the variability that turbulence changes can produce in the neutral and ionic species distributions. It is demonstrated that diurnally varying photodissociation of O_2 around 125 km causes significant upper mesosphere and thermosphere diurnal oscillations. Comparison of the theoretical O/N_2 ratio with

satellite measurements (Kohnlein et al, 1975) show good agreement in amplitude and phase. Utilization of the photoelectron fluxes as well as the photon fluxes for ionization in the diurnally varying chemical-transport model permits a reasonable calculation of sunrise electron density distributions, and predicts a daytime ionospheric "C" layer around 60 km. Varying the intensity of the lower thermosphere-mesosphere turbulent diffusion coefficient demonstrates that turbulence can cause significant variability in the electron density distribution in the thermosphere. The theoretical diurnal behavior of N_m (the amplitude of the F-layer peak electron density) compares quite well with that measured by incoherent scatter radar at Millstone Hill for the condition that the turbulent diffusion coefficient is three times the minimum diffusivity determined in the ALADDIN I Program.

The analysis of the photographic records of the "through-the-night" series of chemical trails in the ALADDIN 74 series at Wallops Island for the presence of turbulence and its intensity has been completed. The results show that from sunset to sunrise, the turbopause shows no altitude variability. However, the turbulent rate of dissipation, determined from spectral analysis of the tracer density fluctuations, exhibits significant nighttime variations, with a minimum of intensity occurring in the post-midnight period. The values of the rates of dissipation determined range from 2×10^{3} ergs/gm sec to 5×10^{4} ergs/gm sec.

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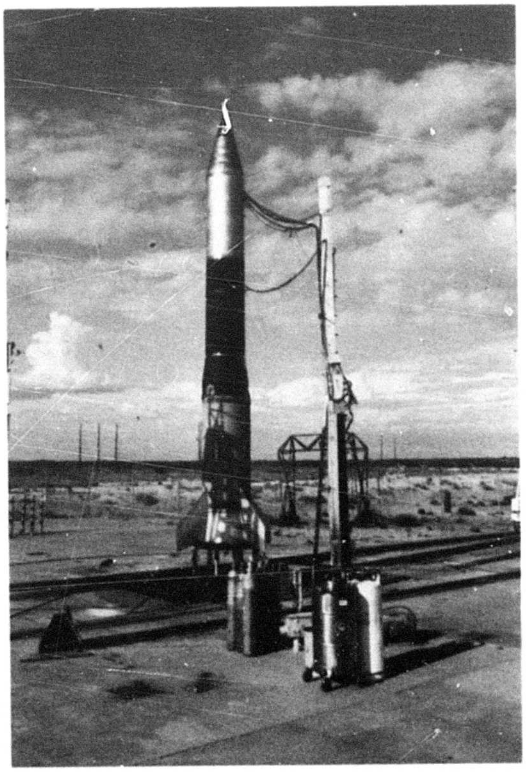


Aries Vehicle at WSMR.

III AEROSPACE INSTRUMENTATION DIVISION

The Aerospace Instrumentation Division has the special responsibility of providing AFGL experimenters with the rocket, satellite, and balloon platforms they need to conduct their experiments. For many years, AFGL's balloon branches were also called upon to assist the Army, the Navy, NASA, and other government agencies who found balloon-borne experiments the most effective way to obtain their data. The Sounding Rocket Branch, which had in the past served AFGL experimenters exclusively, was given missions supporting the Space and Missile Systems Organization, and the Defense Nuclear Agency. A research and development program, although limited during this reporting period by reductions in funds as well as personnel, is also carried on to help insure that the most current, reliable and cost effective technology is available to the scientists and engineers of using organizations. To accomplish this mission, the Division's manning consists mainly of engineers and technicians, both military and civilian.

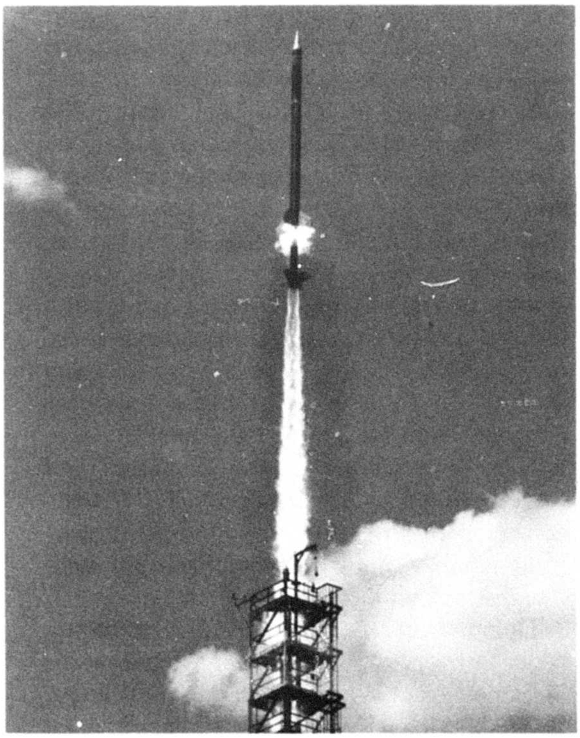
During this reporting period, 18 sounding rockets were flown. Nine of these were launched from White Sands Missile Range, New Mexico. Five were launched from Kwajalein Missile Range, Micronesia Trust Territory, two from Poker Flat Research Range, Alaska, and two from NASA Wallops Flight Center, Virginia.

The Division operates and mans a permanent balloon launch facility at Holloman AFB, New Mexico. This function includes a permanently equipped and maintained tethered balloon facility located in the northern section (Fair Site) of the White Sands Missile Range.

RESEARCH ROCKETS

The Sounding Rocket Branch of the Division is responsible for management of rocket-payload systems, payload engineering, fabrication, test, launch support, data acquisition and trajectory information.

The Division also provides engineering management of the sensor-satellite interface for those satellites on which AFGL scientists are providing sensors for scientific investigation. This involves interface management starting with design and fol-



A Hi Hi Star Launch.

lowing through the fabrication, testing and pre-launch phases. During this reporting period, the Division, working with the Space Physics Division, began the design of its first Space Shuttle experiment package. Engineering research is also conducted in instrumentation, data handling and flight systems to improve existing techniques or advance the state of the art.

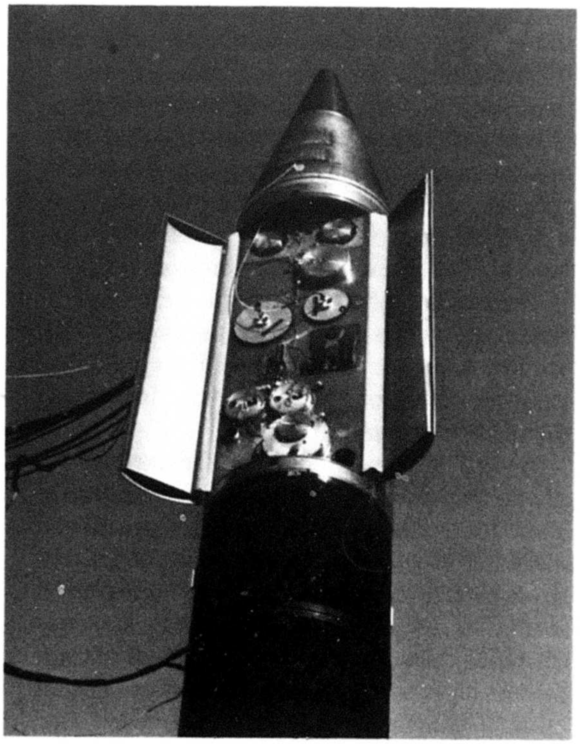
The Division launched its first Aries sounding rocket during this period. The Aries is a single stage rocket capable of carrying heavy payloads to high altitudes. It is a surplus second stage motor from the retired Minuteman I system. The unique features of the Aries are its relatively low cost and its guidance. The guidance allows high altitude flights from restricted ranges like White Sands Missile Range with adequate control to keep impact within established Range boundaries. This is presently the only guided sounding rocket. The previous guided sounding rocket was the German V-2, used by AFGL in the late 1940's

The past two years have seen not only the advent of the Aries sounding rocket but also much more sophisticated payloads, many new state-of-the-art scientific sensors, and modern data transmission systems unheard of just a few years ago.

Auroral Measurements: Two launches were conducted from Poker Flat Research Range, Alaska to measure infrared radiation from the aurora. An IR field widened interferometer was launched for the first time aboard a Sergeant rocket in November 1977. This payload was successfully recovered and refurbished for another flight in 1978. A 500-pound, multi-instrumented IR chemistry payload was successfully carried to an apogee of 450 km aboard a Sergeant-Hydac rocket in February 1978. This payload featured a fully instrumented nose cone that was ejected from the main payload to make separate *in situ* measurements.

Spacecraft Charging: Spacecraft charging effects were studied with the flight of a 377-pound payload on an Astrobee F vehicle at White Sands Missile Range in January 1978. This payload successfully tested engineering models of SCATHA Satellite experiments SC4-1 and SC4-2 which varied the payload charge by emitting a sequence of electrons and positive ions. There were 11 pyrotechnic-activated mechanisms on the recoverable payload; these included four doors, two booms, the nose tip, despin unit, camera, and vacuum sealed experiment packages. A pneumatic actuator was used to separate the payload from the burnt out sustainer at approximately 8 feet/second.

Multispectral Measurement Program (MSMP): The first Air Force Aries vehicle was launched in November 1977. This guided rocket carried the 3200-pound, dual module, TEM-1 payload 227 km above White Sands Missile Range, the heaviest Aries payload flown to date. A complex array of 11 experiments gathered data on rocket motor plume characteristics and backgrounds. The 1100-pound target engine module was successfully recovered after completing all scheduled burns and functions.



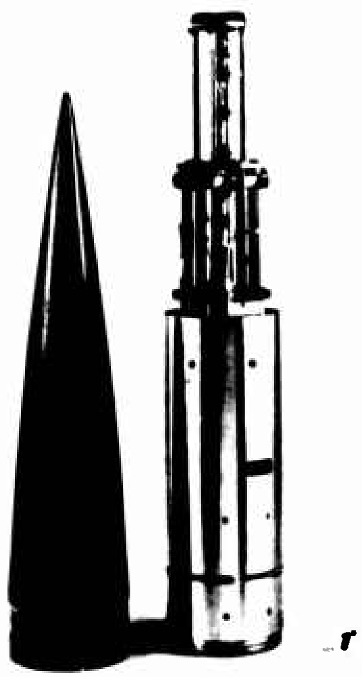
MSMP Sensor Module.

Recoverable Sustainer: The first AFGL recovery of a sounding rocket sustainer was accomplished in April 1978. A sustainer recovery system returned the liquid propellant Aerobee 170 intact to the desert floor after a 190 km science mission above White Sands Missile Range. Aerobee sounding rockets, employed in over 1,000 missions to date, are highly valued by the scientific community for their clean burning, non-outgassing, reliable performance. As this vehicle is now out of production, refurbishment of this sustainer will continue the AFGL capability of providing these rockets for outgassing sensitive experiments. All future AFGL Aerobee flights will utilize this recovery system.

Engineering Research: Advances in instrumentation used in today's experiments require continuing improvements in the subsystems this division utilizes to support our science divisions. It is of no advantage for a scientist to develop a highly accurate instrument if equal accuracy is not maintained in the telemetry, trajectory, attitude control and other critical subsystems for which this division is responsible. The efforts conducted in this period include both in-house work units and specific program sponsorship to improve the state of the art.

Telemetry Instrumentation: Telemetered data from a research probe is one of many essential elements of a successful rocket, satellite or balloon experiment. State-of-the-art advances in instrumentation used in today's experiments require continuing improvements in accuracy and resolution of transmitted data. The Balloon Altitude Mosaic Measurements (BAMM) program is an example of highly complex instrumentation. This program requires a high bit rate pulse code modulation system capable of 14 bit resolution and a buffered data storage for correct data transmission. A unique PCM telemetry encoder was designed with two 1.34 megabit synchronous clocked data links; two identical 1024-word X 14-bit random access memory storage buffers; a 64-frame sub-frame providing both analog and digital data, and a commandable automatic or manual gain selector of 1, 4, 16 and 64 respectively. A patent application has been submitted for the technique of automatic gain selection.

An improved telemetry system has been developed for use with Super Arcas type rocket payloads. The current 1680 MHz receiving systems do not provide reliable tracking and data reception during the entire rocket flight. This new 2200-2300 MHz telemetry system is both lightweight and inexpensive. It includes a flush-mounted stripline antenna, a standard telemetry transmitter, microminiature subcarrier oscillators and a lightweight lithium battery pack. With this design, scientists are able to obtain reliable telemetry support at established launch sites.



Arcas Telemetry System

The recent emphasis on larger diameter rocket payloads such as those used with Aries rocket motors has resulted in the development of several new types of UHF telemetry antenna systems. The typical large diameter rocket payload will contain multiple telemetry links with RF power up to 20 watts for each link. The first acquisition for this project was a reliable RF multicoupler based on our critical specifications. The first antenna system used with the MSMP payload consisted of a number of surface-mounted, stripline antenna sections, mounted around the vehicle nose section and covered with a heat shield.

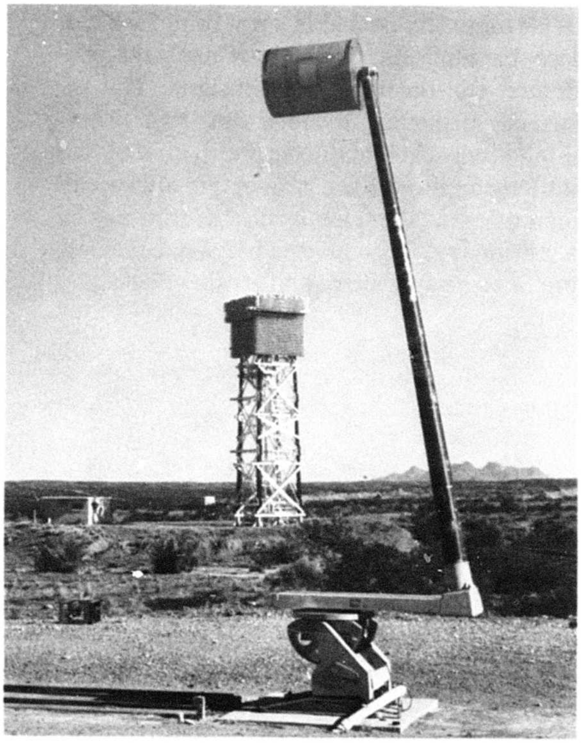
Further in-house study has resulted in three specific antenna systems for future applications. The Survey Probe Infrared Celestial Experiment (SPICE) payload has been provided with a flush-mounted, sealed, stripline antenna system. A lower cost surface-mounted design has been completed and tested, for vehicles with minimal aerodynamic heating. The third concept, used successfully with the MSMP launches, is a single stripline section of antenna that provides a low cost, directional system for use with stabilized vehicle payloads. A microprocessor-based adaptive telemetry system is being developed. This system will evaluate the signal level received from the scientific instrument while it is in flight and select appropriate range amplification levels to give the instrument maximum sensitivity.

Trajectory and Tracking: Tracking of research probes and obtaining vehicle trajectory at remote sites from RF tracked and ranging systems have been improved during this reporting period.

A 10-inch sphere was instrumented to support a density measurement program. This design featured an in-house-developed UHF PCM telemetry system and a unique flush-mounted antenna system. A miniaturized C-Band transponder system was included in this payload to facilitate tracking by the radars in use at most rocket launch sites. This payload was launched at Kwajalein Missile Range in support of the SAMSO T-Rep Program. The first successful radar trajectory data from this type sphere was obtained from this launch. This improved trajectory data accuracy will enhance the scientific measurements for this type of experiment.

A small, lightweight UHF telemetry RF

tracker has been developed that weighs less than 800 pounds in packing cases. No package weighs more than 150 pounds and all packages meet the maximum allowable girth requirements for baggage on commercial airlines. The miniature tracking system has been successfully tested at White Sands Missile Range (WSMR) and at Poker Fwat, Alaska. The tracking system performed equally well in desert and arctic environments. An improved version incorporating



SPICE Antenna Under Test.

digital ranging is presently under construction.

Real-time trajectory data is limited at remote launch sites where radar systems are not available. A microprocessor has been added to our current tracking systems to give them ranging capabilities to provide real-time trajectory. A prototype was fabricated and was tested at Holloman AFB, New Mexico, in October 1977. The trajectory of the BAMM balloon flight obtained by this microprocessor system compared very favorably with the WSMR radar trajectory. A version with both hardware and software improvements is currently being developed.

Optical Systems: The BAMM program requires the identification of the terrain while data measurements are being made. The onboard television camera that was selected is a space hardened version of a standard unit. Pre-emphasis of video signals for UHF telemetry transmission to reduce RF bandwidth without losing resolution was developed. Television pictures returned from approximately 100,000 feet have outstanding quality. The television camera utilizes a 10 to 1 zoom lens that corresponds to 30 to 300 mm focal length. Objects less than 100 feet are easily identified with this system at 1000,000 feet. The commandable function of the camera, zoom in or out, lens open or closed, and focus, far or near, are important features in obtaining high quality television pictures.

Celestial Aspect Sensor: An aspect system that telemeters the position and brightness of stars within its two optical fields was flown on September 28, 1977 from Poker Flat, Alaska. This unit was a prototype developed to provide high accuracy (one tenth of a degree) attitude data with narrow bandwidth telemetry requirements. The unit was to work with both day and night backgrounds. In spite of difficulties with solar scattering from a light leak, the unit detected the positions of both Mars and Jupiter, providing mission-saving attitude data for the scientific measurements.

Vehicle Systems: The addition of the Aries rocket to the available inventory provided the means to fly a new generation of large, sophisticated payloads. It also resulted in problems associated with any new development. Two significant areas of concern that had to be addressed were the boost phase environment a payload would be subjected to on this huge rocket and the terminal environment these large payloads would have to survive to justify their initial expense by being refurbished and reflown.

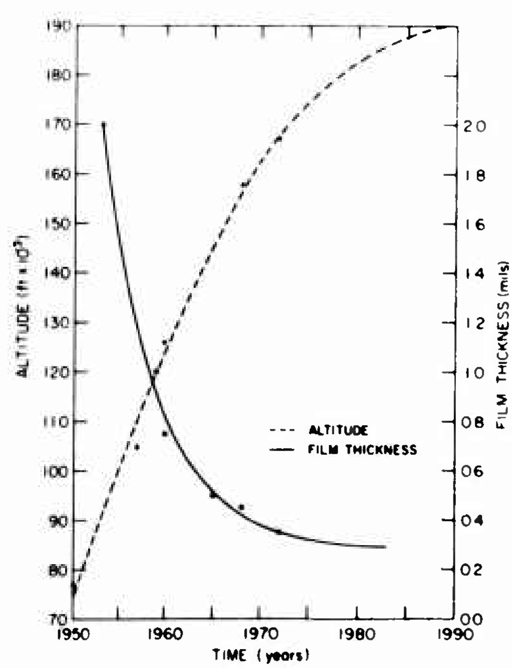
The Aries flight environment was studied by means of vibration instrumentation flown on the MSMP/TEM-1 payload. The data gathered was analyzed on our computer based vibration test facility. The resultant data has increased our ability to project the environment that this class of payload will be likely to see, and test payloads to ensure that they will survive. A reentry design handbook was developed to assist the design engineer in predicting the worst case aero/thermo environment early enough in the design phase to avoid being locked into marginal configurations.

RESEARCH SATELLITES

The Division is responsible for technical management of AFGL research satellite programs and acts as a central point for spacecraft expertise. An additional role of the Division is to act as an interface between aerospace contractors and personnel from satellite control and launch facilities during the integration and testing of a spacecraft. This role extends to the training of scientists, engineers and control center personnel in developing alternate control procedures to achieve mission objectives if and when an anomaly occurs. During this reporting period, three research satellite programs were provided management and engineering guidance from Division personnel. The first of the efforts, S-77-2, has been launched and its mission completed. All of the AFGL experiments worked satisfactorily. The remaining two programs, S-78-1 and S-78-2, are in the final phases of prelaunch preparations. Both spacecraft are scheduled for launch in early 1979. The S-78-1 satellite will have an AFGL electron energy experiment that will make measurements in the auroral oval. The remaining spacecraft S-78-2, SCATHA, has experiments which will vary spacecraft charging by emission of electrons and positive ions.

FREE BALLOONS

The Division conducts free balloon research and development programs which improve the Division's balloon capabilities and benefit the Air Force. The capability analyses discussed in the last AFGL *Report on Research* had already caused a search for more efficient balloon designs to be started. The historical progress in developing thinner balloon grade polyethylene and the resulting improvements in altitude performance were included in the analysis to determine the probable growth of free balloon capabilities. These new analyses confirmed the need for new designs. The research program focused on two interdependent aspects of the problem: a better understanding of the properties of the balloon materials and analyzing the stresses on a stationary, fully inflated balloon, considering both temperature and strain effects.



The Development Trend for Thin Balloon Grade Polyethylene Film and its Attendant Impact on Altitude.

The materials study produced accurate one-axis stress-strain characteristics of present balloon films for use in design and analysis computer codes. The work also proved that the response of balloon film to stress depends on the stress-temperature history of the film, while the assumption of a simple model for time-temperature substitution (equivalence) has been shown to be incorrect. These determinations have been accompanied by improvements both in test methods and in computational analyses for determining biaxial stresses. Recent heavy-load balloon performance combined with the foregoing conclusion suggests that the next step in materials research is biaxial time-temperature stress characterization of balloon films. This will permit more efficient and reliable use of existing materials.

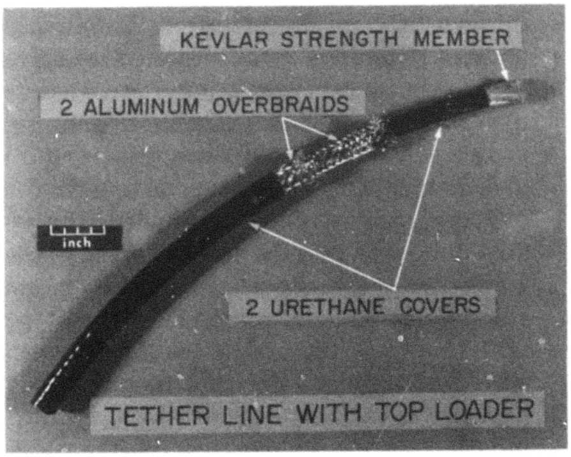
In the study to develop new design criteria which will result in more efficient balloons, computer codes which model the reponse of linearly elastic materials to stress principally along the length of the material (over the range of temperatures the balloon will encounter) have been written and tested. They show that previously computed stresses were inaccurate and that more efficient designs are possible.

While consulting on the analysis of the failure of a NASA balloon, AFGL's suggestion that failure propagation might result in detectable directional evidence was accepted and evaluated, and now is the basis for a significant study by NASA.

Finally, a design study for a system to start the controlled descent of a balloon almost instantaneously was begun. Such a system will allow recovery of high altitude payloads with lower shock and will improve the system response time for descent sampling programs.

Tethered Balloons: In 1975, the Tactical LORAN System Program Office of the Electronic Systems Division asked AFGL's Aerospace Instrumentation Division to investigate the feasibility of using a tethered balloon to support a *Lo*ng *Ra*nge *Na*vigation (LORAN) antenna. They wanted a backup antenna system for a 400-foot tower if the tower should be destroyed by sabotage, hostile action, or violent weather.

The Aerospace Instrumentation Division has been working on the design and test of this balloon-borne antenna for the last two years.



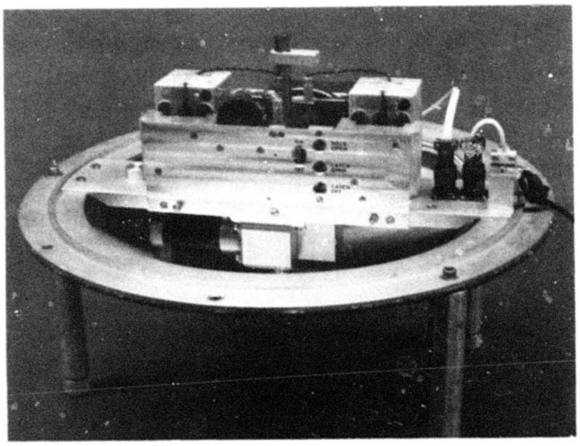
Balloon Tether Line with Top Loader.

The tethered balloon antenna system designed uses a 45,000 cubic foot aerodynamically shaped balloon.

The balloon-borne antenna has an aluminum center element and three top loaders. The center element is made of stranded wire coated with two heavy layers of corona dope and covered with shrink tubing. The coatings and covering were added to prevent corona discharge. The three top loaders were fabricated by overbraiding two layers of aluminum wire on the three balloon tethers. This overbraiding was applied over 700 feet of the tethers' 788-foot length. The tritethers and the 500-foot balloon tether are made of Kevlar.

Normally on tethered balloon flights a UHF instrumentation package is flown to control operation of valves and experiments and to telemeter data. It was realized that such a control package could not be flown on this balloon antenna configuration because the sensitive receiver would almost certainly be made inoperative by the strong radiation and inductive fields from the antenna. Unexpected balloon valve operation and tether cable release might also happen because diodes in the circuitry could rectify the strong signals that are picked up and cause relay closures.

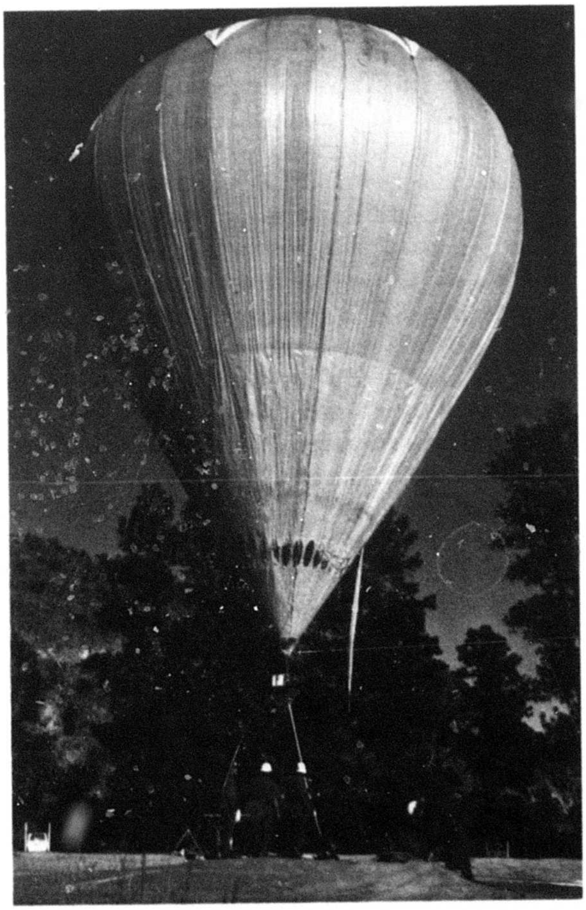
The Division designed a "Smart" gas valve to control balloon operation. This is a modified conventional valve equipped with its own battery power source. An integral aneroid operated switch locks the valve open if the balloon breaks away and exceeds a preset altitude. A differential pressure switch senses internal balloon gas pressure and momentarily opens the valve until the overpressure is relieved. Building the instrumentation into the valve eliminated the cumbersome safety package altogether, and thereby simplified the rigging by removing both the long electrical cables and the pressure sensor inlet tube that tie the safety package to the valves and balloon. Removing the long wires also eliminates the possibility of induced voltage in the wires from the strong electromagnetic fields from the antenna.



Balloon "Smart" Valve

In March 1977, the prototype tethered antenna system was deployed at Holloman AFB, New Mexico, for measurement of the antenna electrical properties and test of the mechanical integrity of the antenna system parts. Electrical parameters measured included input impedance, radiation resistance, and effective antenna height.

On June 20 and 21, 1978, the balloon antenna system was fully deployed at the Master TRN-39, LORAN C/D ground transmitter site, located at Fort McClellan, Anniston, Alabama.

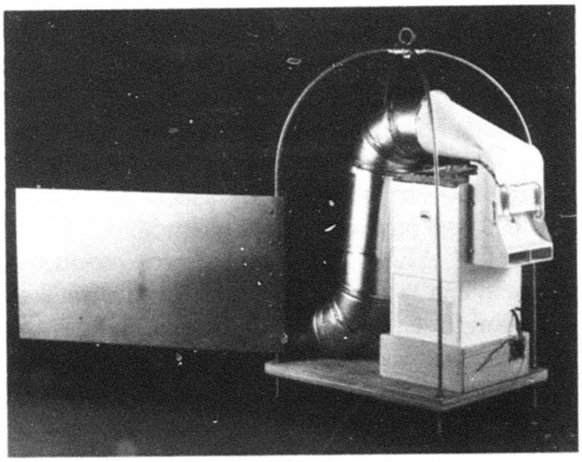


Antenna Shock-Wave Tests at Los Alamos Scientific Labs.

The balloon antenna was powered from the tower transmitter, and current and signal strength measurement made. These measurements have been analyzed and preliminary results indicate a power output of 10 kilowatts as monitored by the evaluation station at Eglin AFB, Florida, approximately 250 miles away. Sixteen hours of measurements and testing were completed on the first day. On the following day, the system was recovered in four hours. During the time from launch to recovery, the weather was good with winds never exceeding 10 knots.

Another tethered balloon program requiring considerable development effort was conducted for the Los Alamos Scientific Laboratories during the fall of 1977. Antenna shock-wave testing was to be conducted so that non-conducting tether cables and very fine antenna stability were required. A special tri-tether antenna apex tetrahedron deployment device had to be designed, fabricated and tested. A recently developed laboratory system of high strength Kevlar cables was used to produce the required non-conductive and stable balloon tether. A special balloon deployment system was also utilized in this very mountainous terrain since conventional winch vehicles could not be brought into the area. Two weeks of successful testing were concluded in November 1977 using a 28,000 cubic foot natural shaped balloon.

Work was begun on the development and fabrication of a special atmospheric sensor to be flown on a tethered balloon. The tethered balloon system and sensor will be used to support an Air Force Communications Service (AFCS) requirement to measure refractive index in the Tyndall AFB, Florida, area. The objective is to determine if microwave signal fade can be correlated with changes in atmospheric parameters, especially refractive index. Conventional radiosondes could not be used since they are commutated by the changing pressure of a rising balloon on which they are commonly flown. A special time-commutated sonde was modified by adding a ventilation blower and duct system. A 35 CFM blower was fastened inside the exit end of the ducting to provide sensor ventilation since the tethered balloon would not have the usual ascending balloon air flow. Rechargeable batteries were used in place of the conventional water-activated type to power the sonde instrumentation and ventilating blower. The system will be capable of sensing continuously for 25 hours before battery recharge is required. Testing in Florida is to begin in October and continue for three months.



Time Commutated Radiosonde with Forced Ventilation.

LOW VISIBILITY MEASUREMENTS

The Division supported the U. S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, in the conduct of its experiments to measure fog particle size in Meppen, West Germany. One series of experiments required a tethered balloon system to carry a 50-pound payload to 1500 feet above ground. The system was designed and a 6,000 cubic foot balloon, lights, tether cable and winch were furnished. Since it was not possible for AFGL to send a balloon crew to West Germany in February, 1978, an Army crew was trained to use a simplified tethered balloon system. Four training flights were conducted at WSMR in December 1977.

AIR LAUNCHED BALLOON SYSTEM

An extensive series of flight tests was carried out on the Air-Launched Balloon System (ALBS) development program. Upon completion of the tests, the designs of major system components were firmed in a redefinition phase. This progress has led to the present construction of a new "hardened" version of the ALBS prototype unit. Present plans call for the new unit to be launched in November 1979 from a C-130 aircraft flying at 25,000 feet over the White Sands Missile Range. After launch the complete mid-air inflation procedure will be carried out, followed by ascent of the balloon and payload to float altitude.

The ALBS flight tests were conducted principally at the National Parachute Test Range, El Centro, California, under the auspices of the Air Force Flight Test Center. Fourteen tests were conducted there, between February and October 1977, in which a test vehicle, simulating the ALBS unit, was dropped from a C-130. Initial drop altitude was 10,000 feet; later, it became 25,000 feet. (Air speed was 132 kt.) A dummy balloon was employed during the first half of the test series. Successful deployments of the dummy led to use of a real balloon in the latter half, including limited inflation testing. The tests showed that, although the designated parachute system could safely extract the ALBS module from the aircraft and deploy the balloon for mid-air inflation, improvements in system reliability were needed.

A full-scale live test of the system was attempted in January 1978. In this test a carrier balloon was to drop the ALBS module from 25,000 feet over the White Sands Missile Range, followed by full inflation and ascent of the ALBS balloon. Unfortunately, this test was aborted because of problems with the carrier balloon. Extensive resultant damage to the ALBS cryogenic inflation unit prevented a repeat test.

Air Launched Balloon System.

IN-FLIGHT BALLOON CRYOGENIC GAS REPLENISHMENT SYSTEM

The feasibility of employing a cryogenic storage system to replenish inflation gas lost daily on long-duration scientific balloon flights was studied in-house. Such a system, in which liquid helium is vaporized and directed into the balloon after sunset each day, could dramatically improve the cost-effectiveness of present long-duration flights. Currently, long flight times are achieved by using large amounts of disposable ballast. This ballast not only constitutes a disproportionate share of the system gross weight; it increases the weight so much that a very large and expensive balloon must be used. The proposed cryogenic gas replenishment system would permit the use of smaller, less expensive balloons.

The in-house studies developed a computer program to calculate the performance of a model system within specified limits. In addition, input and output parameters were identified for use by the Thermophysical Properties Division of the National Bureau of Standards in developing and operating a mathematical model of a theoretical, self-pressurized gas replenishment dewar.

BALLOON INSTRUMENTATION

In response to the increased demand for higher data rates and real-time data reduction, scientific balloon instrumentation capabilities have been tremendously expanded. UHF command and S-Band telemetry systems are providing the flexibility and data collection capability demanded by the scientific community.

A highly flexible PCM instrumentation system, capable of providing complete control of all balloon and experiment operations while maintaining a high data rate, has been designed and built. This equipment is now operational together with a new mobile, minicomputer-equipped PCM ground station. This system provides the user complete quick look and hard copy data display capability, utilizing a computer for real-time data reduction and experiment control, available for world-wide deployment.

A significant addition to the PCM capabilities has been the acquisition of a microprocessor-based decommuntation system. This processor is portable. It facilitates ground system checkouts in the user's laboratory and, together with a receiver and recorder, can serve as a complete portable ground station.

These improved data acquisition systems have successfully supported a wide variety of balloon missions from remote operating locations in South Dakota, New Mexico, Texas, and Alaska.

A new HF instrumentation system has been developed for use where high data rates are not required or as a backup to line-of-sight limited PCM telemetry. This improved HF capability is important to the user because of its relatively low cost, the simplicity of the ground equipment required, and its ability to operate far beyond the horizon. The new HF system is capable of controlling 18 balloon and experiment operations, transmitting 28 channels of data, and providing the user a timed, hard copy visual record of experiment data. This system utilizes a new laboratory-designed and built data encoder with a measurement resolution capability of less than 10 millivolts.

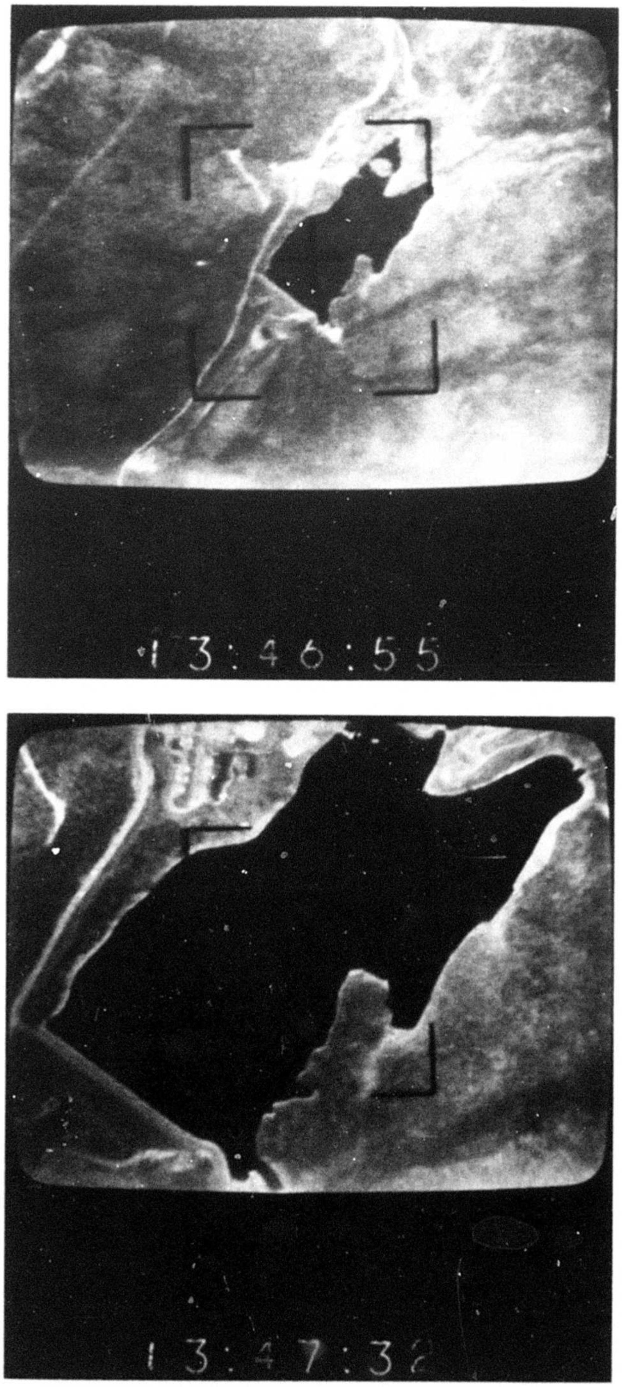
A new VHF, FM transmitter has been designed and built in-house. This modular unit provides vastly improved reliability characteristics in a rugged, low cost design. It was developed specifically for use with the new encoder to provide the user a higher data rate than standard HF equipment at a cost significantly below that of PCM equipment. It has been flown successfully a number of times.

Flight tests of the in-house designed and developed BLS-3 (Balloon Locating System) have demonstrated a fix accuracy comparable to radar. The BLS-3 is an advanced balloon-borne locating system utilizing the FAA VHF Omnidirectional Range (VOR) transmitter network. This system has several technical and cost advantages over other locator systems such as radar and transponders. The BLS-3 concept does not require the balloon to maintain line of sight to the balloon control center and can be used independently of other orientation devices or FAA air traffic controllers.

BAMM Balloon Payload Being Returned to Launch Site Following CH-3 Helicopter Mid-Air Retrieval (MAR) Recovery.

PROJECT BAMM

The Balloon Altitude Mosaic Measurement (BAMM) program, to obtain infrared background measurements for use in the design of advanced sensors, conducted three development test exercises during the reporting period. Two were conducted at the AFGL Detachment #1, Holloman Air Force Base site, and one was performed at the Chico, California, MAP Operating Location. The activities culminated in four balloon flights, each resulting in various levels of successful testing of the BAMM payload design. All major sub-systems and functions of the BAMM operational flight system were successfully tested in flight. These included making actual measurements using the specialized infrared and video components, and in-flight recovery of the development-test payload by CH-3 helicopters utilizing the Air Force Mid-Air Retrieval System technique. Operational flights and data gathering are planned for the second and fourth quarters of 1979.



Transmitted Pictures from BAMM.

PROJECT STRATCOM

The Division furnished balloon flight and technical support to a joint atmospheric measurement program involving the U. S. Army Atmospheric Sciences Laboratory, ERDA and NASA. Data derived from these balloon flights have provided information for a correlated study of stratospheric composition, dynamics and thermodynamics between 20 and 38 km altitude.

Two missions were flown during Septembej 1977. The first flight on September 28 carried a payload of 1,500 pounds consisting of seven experiments, to a peak altitude of 92,000 feet. After a six-hour flight, the payload was recovered a few hundred miles northeast of the launch site, Holloman Air Force Base. A second flight of 32 hours began on September 29 and carried 24 experiments to an altitude of 126,000 feet.

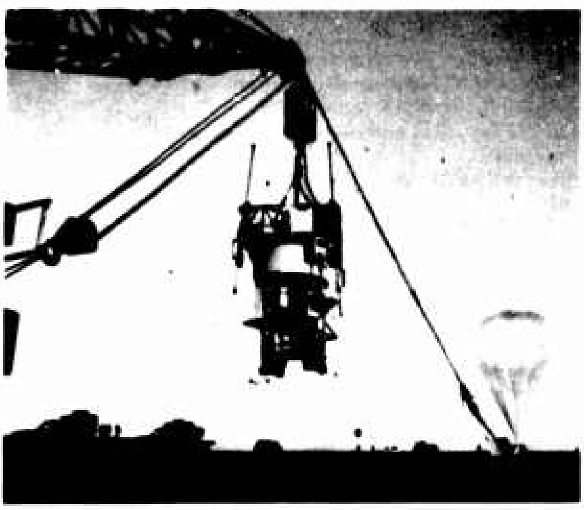
Results obtained will provide further understanding of the transport and extent of atmospheric pollutants and their threat to human activities. Of particular importance will be measurements of Freon which recently has caused concern because of its possible effects on the atmospheric ozone balance.

ATMOSPHERIC SAMPLING PROGRAMS

For a number of years, the Aerospace Instrumentation Division had been providing balloon operations support to atmospheric sampling programs of the Department of Energy, NASA and the Army. With the reduction of personnel at AFGL Detachment 1 and deactivation of AFGL Detachment 3, Chico, California, in June 1976, Headquarters AFSC directed this support be contracted out with AFGL acting as technical monitor. In October 1976, the Physical Sciences Laboratory of New

Mexico State University was awarded this contract and, after a period of training, began providing operational support to the sampling programs. Fifty balloon flights were conducted from Holloman Air Force Base, Panama and Alaska. The latter two locations required aerial recovery of the payloads by C-130 aircraft

Project "Ash Can," one of the sampling programs, provides measurements of radioactivity, fluorocarbons, chlorine and other atmospheric constituents which have or could have an impact on health. A notable achievement occurred when measurements were obtained on atmospheric radioactivity caused by the reentry of the Russian COSMOS satellite. Combining Ash Can flight series at Alaska and Panama with AFGL's sampling program has reduced travel, per diem, and transportation costs to AFGL. AFGL benefits from work conducted under the Ash Can program in the areas of rigging, command and control, and systems integration.



BAMM Flight System Ready for Launch.

PIONEER-VENUS DROP TESTS

On May 20, 1977, the main probe for NASA's Pioneer-Venus mission was successfully tested by releasing the probe from a balloon, 27 km above White Sands Missile Range. All test objectives were met and the probe was qualified for Venus entry. The test consisted of deployment of the probe parachute, separation of its atmosphere entry heat shield; and, after nine minutes of parachute descent, separation of the parachute for simulated flight down to Venus's surface.

AIR FORCE GEOPHYSICS LABORATORY SCIENTIFIC BALLOON SYMPOSIUM

The Ninth and Tenth Air Force Geophysics Laboratory Scientific Balloon Symposia were held at Wentworth-By-The-Sea, Portsmouth, New Hampshire, during October 20-22, 1976 and August 21-23, 1978. These meetings were attended by large numbers of engineers and scientists affiliated with government, industry, and universities from the United States and several foreign countries. Sessions were concerned with scientific balloon operations, balloon technology, manned flights, balloon-borne experiments and instrumentation, and airships. The Keynote Address of the Tenth meeting was given by Dr. Hans Mark, Under Secretary of the Air Force. Proceedings of the ninth meeting have been published and the proceedings of the tenth meeting are in the process of being published. A total of 63 papers were presented at these meetings.

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CARTEN, A. S., JR.
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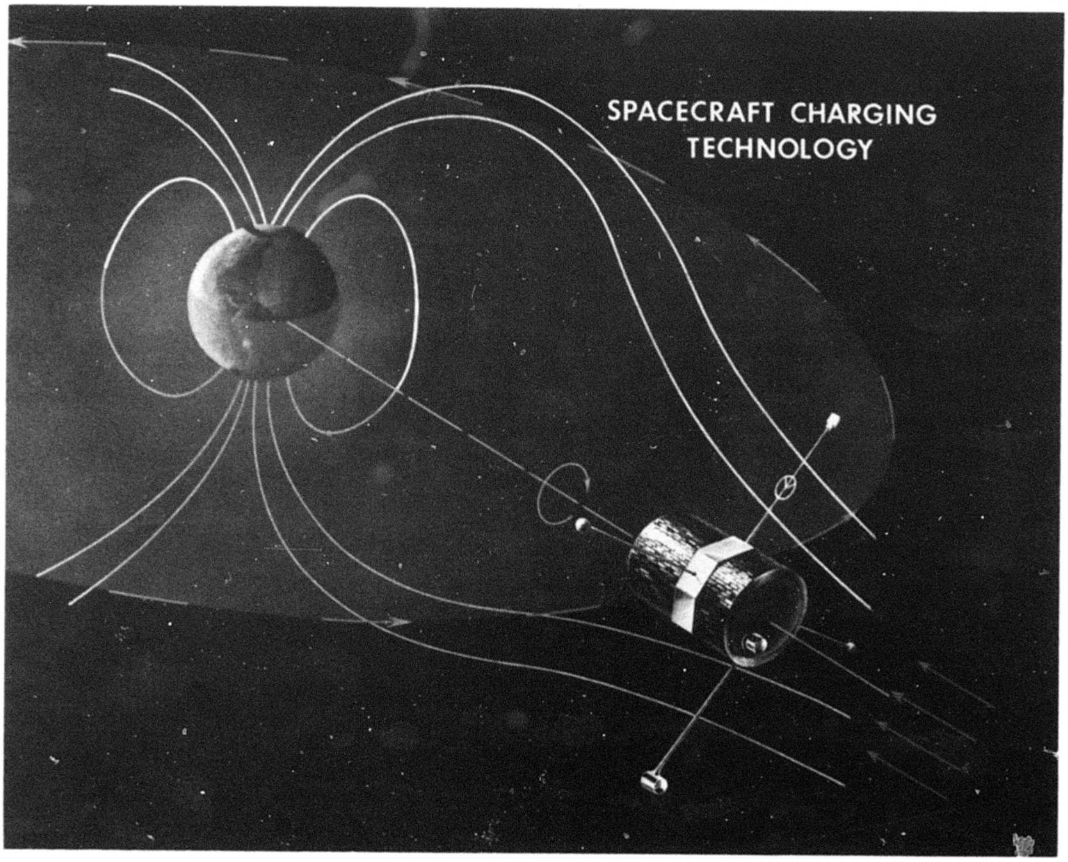


The SCATHA Satellite, showing the arrangement of booms, the orbital plane close to the ecliptic, and the spin axis maintained perpendicular to the earth-sun line.

IV SPACE PHYSICS DIVISION

The technical program of the Space Physics Division is concerned with space environment effects on Air Force systems. Particles, such as electrons and protons, which permeate near-earth space, can degrade satellite electronics and sensors by radiation damage, and they can interfere with and disrupt on-board computer systems. Magnetic storms and sub-storms create ionospheric disturbances which degrade communications to and from satellites, and which can cause surveillance, detection, and tracking systems to become ineffective or to give false information. Space is a dynamic environment with daily and seasonal variations and with naturally occurring disturbances. These variations and disturbances are caused by the sun. Therefore, the Division's program deals with the phenomenon of solar activity and how to predict it. It is concerned with the radio and particle emissions resulting from such activity and with the propagation of solar particles through the interplanetary medium to the vicinity of the earth. It deals with the interaction of such particles with the earth's magnetosphere, and with the particle fluxes and energies within the magnetosphere. It includes investigation of magnetic disturbances and storms and ionospheric irregularities resulting from particle precipitation and varying electron densities.

In accomplishing its programs, the Division observes and monitors the important parameters in near-earth space with instruments carried by satellites and by a dedicated, heavily instrumented KC-135 which functions as an airborne ionospheric observatory. The flying observatory is used in a program of ionospheric mapping and in the study of ionospheric disturbances both in the arctic and in the equatorial regions.

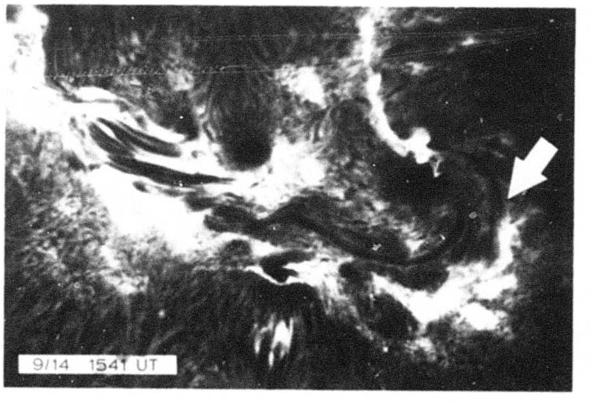
To complement the satellite and aircraft-borne observations, the Division maintains a number of ground-based observational sites such as the radio observing site at Sagamore Hill, Massachusetts, the ionospheric observatory at Goose Bay, Labrador, its network of seven magnetic disturbance monitors across the United States and its Solar Research Branch at the NSF-operated Sacramento Peak Observatory.

THE SOLAR RESEARCH BRANCH

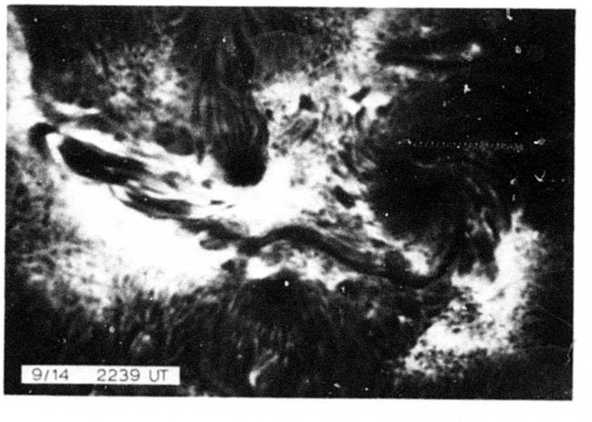
The Solar Research Branch is located in Sunspot, New Mexico, as a tenant at the Sacramento Peak Observatory (SPO), which is a national center for solar physics operated by the Association of Universities for Research and Astronomy, Inc., under contract to the National Science Foundation. The task of the Solar Research Branch is to identify, predict, and understand the physical mechanisms on the sun which give rise to solar flares and high speed solar wind streams, because these are the phenomena which produce environmental disturbances that disrupt Air Force systems. In addition, the Solar Research Branch is now pursuing methods to restore images which have been degraded by atmospheric turbulence, and is just beginning a study of variations of the sun's ultraviolet output to determine if these changes are large enough on a short enough time scale to affect the character of the ionosphere or influence weather patterns.

Flare Prediction: A major portion of the solar research carried on by the Branch is dedicated to the physics of solar flares and to the solar conditions leading to flares. The efforts are directed along two distinct avenues: a statistical approach toward an objective flare forecast, and a detailed study of the physical processes associated with flares. Both approaches utilize solar data obtained from the Air Weather Service Solar Optical Observing Network (SOON) in addition to the telescopes available at Sacramento Peak Observatory. The techniques developed through these studies are, in turn, applicable to the SOON observing sequences and to the operation of the international forecast center in Boulder, Colorado (a part of the National Oceanic and Atmospheric Administration (NOAA)).

The statistical approach to solar flare forecasting incorporates a procedure known as Multivariate Discriminant Analysis, in which about thirty daily-observed solar par-



(a) Solar flare on September 14, 1977. Note twisted dark fibrils on right side at arrow, indicating energy buildup. In (b), taken seven hours later, the fibrils have relaxed into a more radial configuration.



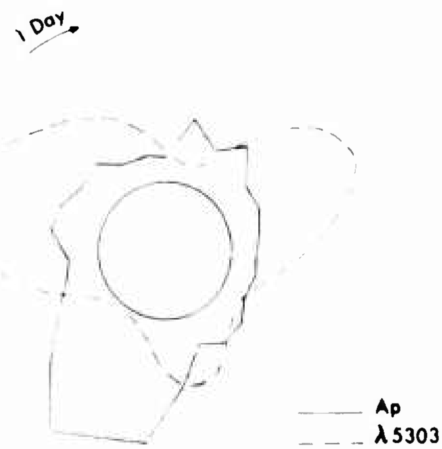
ameters are compared with the magnitude of flare activity the following day. The Multivariate Discriminant Analysis computer program has the ability to maximize the discrimination between possible activity outcomes (no flare, small, medium, or large flare) in terms of combinations of the input parameters. The program is "trained" on historical data and subsequently applied to future time in which only the input solar parameters are known.

New solar parameters, especially those incorporating the basic processes of flare energy storage and release, are being studied by the Solar Research Branch. Observations of sunspot motions and active-region geometry have proven useful in tracking the buildup of energy in sheared magnetic fields. The configuration of the hydrogen-alpha fibril structures indicates the state of shear in a flare-producing region and may be used to estimate the upper limit on the energy released by any subsequent flare at that location.

The real-time capacity for a display of the motions of all sunspots in an active region is being developed jointly by Solar Research Branch and Air Weather Service personnel, and will be generated by SOON telescopes for use at the forecast center.

The advantage in pursuing simultaneously both the statistical and the physical approaches to flare prediction is that Multivariate Discriminant Analysis can test the relative significance of possible new input parameters in terms of the success of previously used parameters.

Geomagnetic Disturbances and Coronal Holes: To help the Air Weather Service predict geomagnetic activity, the Solar Research Branch has developed an observing program to locate coronal holes on the sun. These regions of low density and temperature in the corona are sources of recurrent high-speed streams of solar wind. The impact of these streams on the geomagnetic field disturbs the field. Thus, if coronal holes can be detected reliably, recurrent geomagnetic disturbances can be predicted up to ten or more days in advance of their occurrence. The most reliable way to detect them is from full-disk solar pictures taken in x-rays from rockets or satellites. This is not feasible for long-term monitoring. However, optical monitoring of the corona is possible on an almost daily basis, and a collaborative study done by Solar Research Branch and Sacramento Peak Observatory personnel showed that this type of monitoring could detect the sources of recurrent geomagnetic disturbances 70-80 percent of the time (compared



A comparison of equatorial 5303 Å emissivities with averaged A_p, corrected for the equinox effect. The day of the largest A_p is November 13, 1976, and time increases in a clockwise direction. A lag of 5 days has been introduced between central meridian passage on the sun and A_p at the earth. The circle represents zero for A_p, and A_p varies from 6 to 35 in this figure. The dashed curve is the average log emissivity, ranging from log 2 x 10^{-11} at the circle to a minimum of log 2.35 x 10^{-10} in this figure. Note the coincidence (at lower left) of the only major recurrent disturbance and the deepest coronal hole. A minor geomagnetic disturbance is connected with another hole at upper right.

with 60-65 percent based simply on 27-day recurrence due to solar rotation). The Solar Research Branch now observes the corona daily (weather permitting) in the 5303 Å line of Fe XIV, and compiles data twice-weekly into maps of coronal brightness and/or emissivity, with coronal holes identified. These maps and accompanying numerical predictions of geomagnetic disturbances are telecopied to Air Force Global Weather Central for use in geomagnetic activity predictions.

Speckle Interferometry: The Solar Research Branch began a major effort to greatly improve imaging through the Earth's atmosphere using the astronomical technique known as speckle interferometry. The ultimate objectives of this project are to improve solar surface images by a factor of ten over those now obtainable and to adapt existing large stellar telescopes to obtain increased resolution on Earth satellites. During this period, substantial progress was made on both objectives.

There are two promising approaches for solar surface image enhancement. A contractor has perfected a method to process solar photographs to produce images with a factor of ten increase in resolution. Solar Research Branch scientists hope to use this technique to study the time evolution of small scale solar magnetic fields. A second method for improving solar images is to use an active-optics device to reconstruct in real-time images free from atmospheric distortion. Using Laboratory Director Funds, the Solar Research Branch has arranged to use such an instrument in conjunction with the Sacramento Peak Observatory Tower Telescope.

The Solar Research Branch has made substantial progress on low-brightness and satellite image reconstruction techniques. Most technical problems are now solved and demonstrations on actual satellites are planned. Three key problems were solved in 1977-1978: developing equipment capable of obtaining data for faint objects, developing methods to calibrate results, and investigating means to produce reconstructed images, rather than just the size and shape of objects as was previously possible. In conjunction with a contractor, the Solar Research Branch constructed a television array camera to record individual photon arrivals at the telescope. This system allows observations of objects 1000 times fainter than previously possible, including most earth satellites. Branch scientists also perfected a computer analysis system to calibrate the results to give quantitative size and shape information for objects too small to image. This system was used to obtain the first direct size measurements of several asteroids, as well as Saturn's moons. Finally, other computer methods to reconstruct images fully were investigated. This method was tested on several objects, including the asteroid Vesta, the surface of which has never been directly resolved. Although the data are of insufficient quality to show surface structure such as craters, one can see that the asteroid is slightly elongated. Work will continue along this line in 1979.

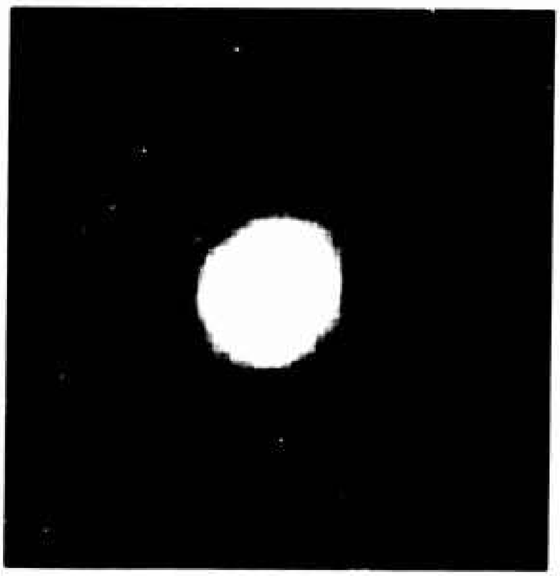


Image of the asteroid Vesta obtained by image reconstruction using the techniques of speckle interferometry and speckle imaging. Note the slightly elongated shape.

Speckle interferometry shows considerable promise for other scientific purposes. Following AFGL analysis, NASA has adopted this technique as one method in searching for planets around nearby stars. The very accurate positions of one star relative to another which speckle interferometry produces will enable NASA to see tiny wobbles in a star's motion indicating a planetary object in orbit around the star. Another possible use of speckle interferometry would be a search for black holes in the centers of galaxies.

Solar Variability: There is mounting evidence that the sun has long and intermediate-term variability in its energy output. These changes may translate into upper atmospheric and weather pattern changes. During parts of the 17th and 18th centuries, a decrease in worldwide temperature accompanied a virtual lack of sunspots. Astronomers at the Lowell Observatory in Flagstaff, Arizona, have reported changes in the outer planet brightness inversely proportional to the number of sunspots. These changes, up to 2 percent per year, are probably triggered by changes in the solar ultraviolet energy output.

To confirm and determine the source of planetary brightness changes, the Solar Research Branch has begun a program under Laboratory Director's Fund support. Due to changes in atmospheric pollutant and transmission parameters, it is difficult to observe solar energy output changes directly. The Lowell Observatory Program avoids this problem by comparing planetary brightness (which presumably represents solar brightness changes) to a large set of nonvarying stars. However, one cannot rule out changes in the physics of the planetary atmospheres causing the apparent brightness change. To check whether the sun itself is varying, Branch scientists have devised observations of objects *without* atmospheres, and also are extending their observations to the ultraviolet spectral region which would have greater effects on the upper terrestrial atmosphere. This effort requires routine access to a large stellar telescope equipped with a good brightness-recording photometer. A surplus 48-inch satellite-tracking telescope facility in Cloudcroft, New Mexico, was acquired to make the measurements.

Generalization of Solar Activity: From studies of the sun alone it is impossible to tell whether solar activity (flares, corona, etc.) is a unique property of the sun. During this period, Solar Research Branch scientists have studied several classes of stars and confirmed the existence of solar-type activity. In fact, the sun exhibits rather low levels of activity relative to many stars.

Two classes of stars have been analyzed in particular detail. Using equipment at the Kitt Peak National Observatory in Tucson, Arizona, high resolution spectral profiles for stars similar to the sun were obtained. Using these profiles with models developed at the University of Colorado has allowed estimates of the physical conditions within the stellar chromospheres. Also studied were the M-dwarf stars, stars smaller, cooler, and much more active than the sun, showing such large flares that the whole star may brighten by a factor of 100. Similar activity on the sun increases the solar brightness by, at most, 1 percent. Yet, we have been able to confirm that this activity is very similar to solar flare processes. This work will be extended using the NASA International Ultraviolet Explorer Satellite. The flare mechanisms will be studied in detail and coronae may be detected around these stars for the first time.

Other Projects: Results were published from joint Sacramento Peak Observatory/OSO-8 satellite studies showing that solar super-granular convective velocity patterns extend upward into the chromosphere/transition zone region. This is the first evidence that steady quiet-sun large-scale motions below the surface can transfer material into the high solar atmosphere. This may be very significant to problems of energy balance, heating of the corona, and interaction of magnetic and velocity fields.

The Solar Research Branch and collaborators at the University of Colorado will continue this work as guest investigators on the FY 79-80 NASA Solar Maximum Mission satellite.

Oscillation observations were analyzed to reveal a non-uniform solar rotation beneath the surface. The source of these five-minute oscillations has been a mystery since their discovery in 1960. Solar Research Branch personnel and their collaborators at UCLA have now explained this phenomenon as non-radial p-mode oscillations of the entire solar convection zone which extends some 200,000 km below the surface.

The first detailed observations of coronal holes were made at radio frequencies. These were compared with X-ray and optical photographs. Modeling of the electron density and temperature of coronal holes has begun as a contractor effort.

Analysis of high-resolution magnetic field observations indicates that probably all solar fields occur in small clumps with strengths of 1000-1500 gauss. Any weak field which might exist must be less than 50 gauss, which indicates that even in the quiet sun at least 85 percent of the magnetic energy in the photosphere resides in strong fields.

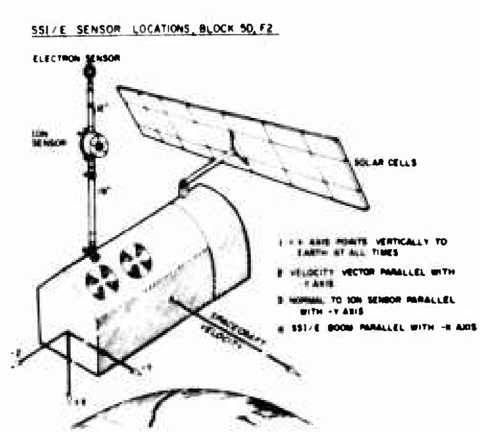
Simultaneous optical and radio observations of a flaring region were obtained. The radio measurements indicate dramatic polarization changes occurring within the hour previous to the flare. A search for the optical counterpart to these polarization changes has begun.

DEFENSE METEOROLOGICAL SATELLITE PROGRAM

Topside Ionosphere Plasma Monitor: The Space Physics Division is supplying a series of Topside Ionosphere Plasma Monitor instruments for flight on Defense Meteorological Satellite Program (DMSP) satellites. They will provide near real-time measurements of the topside ionospheric density, scale height, F-region critical frequency and the nature of small-scale plasma irregularities. These parameters are used in frequent updating of the Air Weather Service model of the topside ionosphere and F-region peak. The model is used in the frequency management of Air Force communications and surveillance systems.

The data on small-scale plasma irregularities is used in the investigation of the scintillation of signals received at the ground from satellites in orbits high enough so that their signals pass through the topside ionosphere to reach the earth. Spatial irregularities on the scale of a few meters to one hundred kilometers in extent cause scattering, deviation and diffraction of these signals. When observed at a fixed receiving station on the ground, the overall effect is called "scintillation" and can cause data loss or total loss of signal from communications satellites. The phenomenology of these scintillations is not yet fully understood and the data acquired will be used both to build up a statistical description of satellite signal scintillations and in studies of the processes forming the plasma irregularities themselves.

The instrument, designated SSI/E, consists of separate thermal energy positive ion and electron sensors mounted on a boom which holds both sensors clear of the disturbed plasma around the satellite. The



Block 5D F2 DMSP spacecraft showing the boom mounted ion and electron sensors.

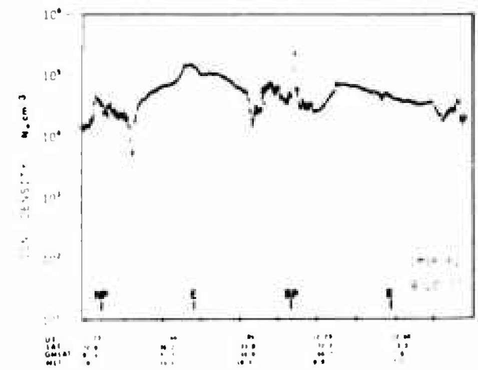
satellite is three-axis stabilized, so that the planar ion sensor faces the direction of travel at all times. Attitude is not critical to the operation of the electron sensor.

One set of instruments was launched in mid-1977 into a dawn-dusk circular orbit. The ion density data at the satellite altitude of 830 km shows several important features. They include: a) relatively smooth variation at midlatitudes, b) highly variable structure in both polar caps and auroral zones, c) the midlatitude trough, seen most clearly in the northern hemisphere, and d) the local maximum and minimum in plasma density observed at the equator, at local sunset and sunrise, respectively.

The nearly continuous measurement of plasma density is interrupted every 128 seconds and a voltage ramp is applied to each sensor. Analysis of the currents drawn to the sensors at these times yields data on ion and electron temperature and spacecraft potential, which are required to determine plasma scale height and hence F-region critical frequency.

DMSP Electron Spectrometer: The Space Physics Division has designed, built and calibrated four electron spectrometers designated SSJ/3 for the Space and Missile Systems Organization to be flown on Defense Meteorological Satellite Program satellites. Two of these sensors have already been flown and two more are awaiting flights. Each spectrometer consists of two electrostatic analyzers. The spectrometers will measure the spectrum of precipitating electrons from 50 eV to 20 keV. The DMSP low altitude (400 nm) polar orbiting satellite passes through the precipitating electrons that are responsible for the aurora. The data from the SSJ/3 instrument is used to determine the boundaries of the auroral oval. Data from the SSJ/3 were used to verify the feasibility of X-ray imaging in the auroral regions.

Electron spectral measurements will be used by the Space Physics Division to relate electron precipitation with substorm phenomena. This effort is being carried out in collaboration with other scientific groups. The SSJ/3 data is available to the general scientific community through the World Data Center at the National Oceanic and Atmospheric Administration.

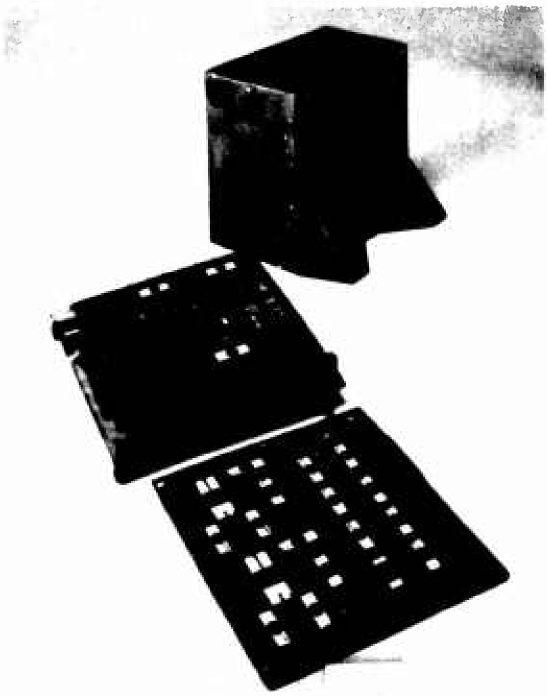


Ion density measurement at 830 km altitude from planar ion sensor on DMSP Block 5D F2 satellite. The smooth variation of the plasma at midlatitudes is in contrast with the rapid density fluctuations over both polar and auroral regions.

A more sophisticated version of the SSJ/3 is on the P78-1 satellite. This instrument gives high resolution pitch angle information for precipitating particles along magnetic field lines.

THE ENERGETIC PARTICLE ENVIRONMENT

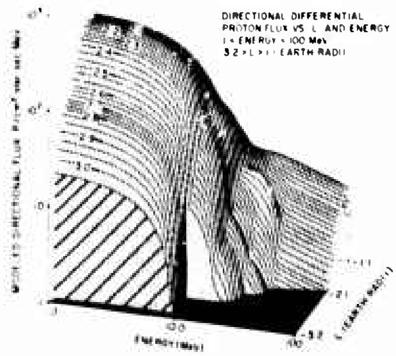
Environmental Effects on Space Systems: The vulnerability of microelectronics to natural radiation limits operational lifetimes of Air Force satellite systems. In recent years, it has become appreciated that Complementary Metal Oxide Semiconductor (CMOS) devices and charge coupled devices (CCD) used in satellite systems to meet weight and power constraints are susceptible to environmental damage. It has been discovered, for example, that some CMOS circuitry is 1 to 2 orders of magnitude more vulnerable to radiation than had been previously suspected. The source of the radiation damage



The SSJ/3 Electron Spectrometer.

is currently believed to be high energy electrons (1.0 - 10.0 MeV). These high energy electrons are difficult to shield against and may increase the radiation dose by an order of magnitude over that previously expected in many orbits that Air Force satellite systems will operate, such as the 60 degree inclination semisynchronous orbit of the Global Positioning System.

At present, the knowledge of the high energy electron environment at satellite altitudes is summarized in the model developed by the National Space Science Data Center. This model is based primarily on observational data obtained between 1959 and 1968, and although the model itself extends to about 4 MeV, very little observational data were available for energies greater than 1 MeV. Because the major portion of the total radiation environment at satellite altitudes is less than 1 MeV, little attention has been devoted to detailed modeling of the high energy portion of the energetic electron spectrum. The existing high energy electron model is not accurate enough in the energy range 1.0 - 10.0 MeV to properly assess satellite electronic component lifetimes. The few observations that are available tend to confirm the suspicion that energetic electrons in the 1.0 - 10.0 MeV range are primarily responsible for enhanced dosage rates. These measurements, however, are neither accurate enough nor numerous enough to generate a realistic model of the high energy electron environment.



Proton flux model based on S72-1 data.

For these reasons, there exists the need to perform *in situ* measurements of the flux of high energy electrons for various levels of solar activity and to incorporate these results into a model that can be used to determine radiation effects on satellite-borne electronic components. This measurement and modeling program needs to be undertaken even if the current Air Force Materials Laboratory program to produce hardened CMOS is successful since the new generation of microelectronics, memory elements and high speed circuits will be vulnerable to electron dosage integrated over a time period commensurate with planned satellite lifetime.

The Air Force Geophysics Laboratory has begun a technical program to develop a realistic model of the high energy electron environment at satellite altitudes. The Program includes four principal efforts. State-of-the-art detection techniques and instrumentation will be developed to measure the particle environment, as rides become available. Dosimeters will be flown on rides of opportunity, such as DMSP, to verify present flux models. A capability to predict dosage/depth relationship for any satellite orbit will be developed. Finally, materials will be exposed to electron and ion beams in a joint effort with RADC/ET which will seek to understand the damage mechanism in microelectronics.

Long Duration Exposure: Trapped proton fluxes are not well determined, and, in fact, long term stability is not yet established. While some measurements indicate a factor of 2 stability over 10-year periods, many measurements indicate either wild fluctuations, instrument inaccuracies or both problems. To predict false signal rates and radiation damage to electronic devices operated in space, the differential energy spectrum of protons greater than about 1 MeV must be known to an accuracy of better than a factor of 2 throughout the radiation belt. Unfortunately, in the 1 to 10 MeV energy interval the inner zone proton fluxes are almost unknown because of background problems. For higher energies great uncertainties still exist and, in general, only integral energy spectral data are available.

An exposure package has been designed to obtain measurements of trapped proton fluxes utilizing the NASA Long Duration Exposure Facility (LDEF). The objective of this experiment is to perform detailed differential energy spectral measurements of trapped protons integrated over the six month LDEF lifetime. In addition, the heavy ion component will be measured and neutron intensities determined. Total dose will be measured and samples of bubble memories will be exposed to determine any adverse radiation damage effects.

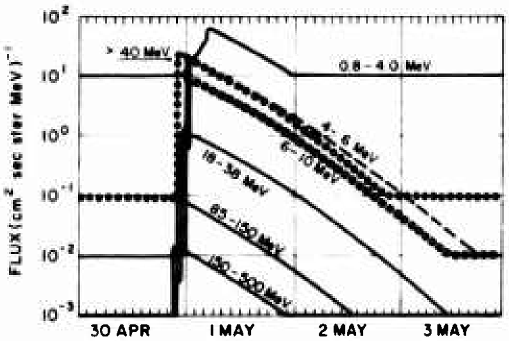
Although the basic techniques are similar to those used in the 1960s to obtain trapped proton fluxes from Air Force recoverable satellites, it has been necessary to develop proton sensitive plastic detectors capable of withstanding the six-month exposure planned for the Long Duration Exposure Facility. Early experimental designs consisted of shielded emulsions with narrow cylindrical openings to allow trapped protons to enter. The recent discovery of the CR39 plastic detector opens up the possibility of a new solution to this problem.

Four cubical containers will be provided in which passive radiation detectors can be arranged and oriented to best detect mirroring trapped protons as the LDEF passes through the South Atlantic Anomaly. Three of these containers will be spaced around the LDEF and one placed on the bottom (earth) side.

The experiment is passive so that no power or signals are required. Thermal control is provided by a white external coating and black internal coating. Some manipulation of thermal coupling of the payload to these surfaces will be performed to avoid temperature excursions above 38 C. The passive radiation detectors - nuclear emulsions, plastics, thermoluminescent dosimeters and activation samples - will be analyzed following recovery to determine proton energy spectra, dose depth relationship and neutron spectra. The bubble memories will be analyzed for radiation induced failure. This experiment offers the potential of obtaining the first reliable measurements of inner zone trapped protons of 1 to 10 MeV as earlier electronic counter measurements are uncertain, and the Nuclear Emulsion Recovery Vehicle emulsion results were for too brief a time interval, in addition to being spatially limited.

Proton Prediction Studies: Proton prediction research is a continuing effort in the Space Physics Division. The results of this research have been combined into a computer prediction technique used by the USAF Air Weather Service Environmental Support Facility and the National Oceanic and Atmospheric Administration Space Environment Laboratory. The techniques in use have been very successful for the

SMS/GOES PREDICTION



Predicted time-intensity profile for the April 30, 1976, solar proton event. This prediction is for the solar proton sensors on the SMS/GOES satellite.

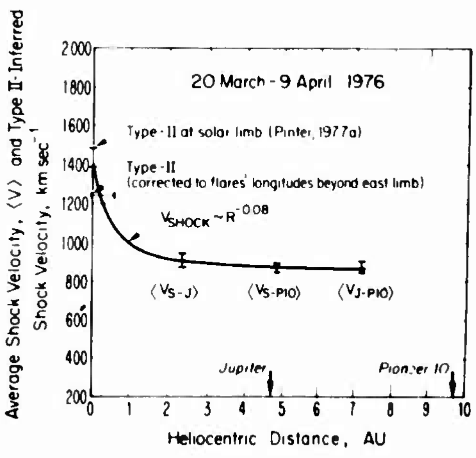
generation of predictions of solar protons responsible for polar cap absorption events or for proton fluxes in the 1-100 MeV energy range. Significant improvements in the accuracy of the forecast were obtained when the techniques to predict the slope of the solar proton energy spectrum were incorporated into the real-time prediction procedures.

The solar particle event of 30 April 1976 was selected for intensive study using this proton prediction program. The computer program developed for the prediction of solar proton events generates predictions of solar proton time intensity profiles expected after the occurrence of solar flares having the distinctive "U-shaped characteristic" in the radio emission that has been associated with earth-sensed solar proton events. This study demonstrated that the technique of selectively adapting concepts from experimental and theoretical studies and then combining them into a procedure designed for practical application appears to be successful.

The predictions for this event were in excellent agreement with the satellite data observations. The ability to make predictions for the exact energy range measured by a specific satellite channel enhances the utility of this prediction technique and allows very rapid comparison of the prediction with actual data observations and also provides for the possibility of updating the forecasts.

Solar Terrestrial Phenomena Studies: The significant solar-terrestrial events from 20 March to 5 May 1976 have shown that even during solar minimum the sun can produce major interplanetary and terrestrial disturbances. A multidisciplinary study of solar interplanetary data led to the first identification of a solar induced interplanetary shock wave at a distance of 9.7 AU. The shock wave apparently rapidly decelerated up to 2 AU with very little deceleration from 2-10 AU.

Solar flare activity during this period was associated with several major geomagnetic disturbances and several significant solar particle increases including a ground-level relativistic solar particle event. This event, with an unexpectedly hard solar particle spectrum, led to a subsequent study indicating that solar particle events producing significant (greater than 0.5 dB) polar cap



Average shock velocities and type II inferred shock velocities. The notation (V_{S-J}), for example, refers to the average velocity between the sun and Jupiter and is plotted midway between these two points. Note the rapid deceleration within 1 AU with nearly a constant velocity inferred thereafter.

absorption during this solar minimum (1975-1977) had harder solar particle spectra than similar events during the previous solar minimum.

The solar and geomagnetic circumstances prior to solar particle increases for the period 1970-1972 were studied. A total of 363 particle events were identified as detected near the earth during this period, 93 of which were proton events with energies greater than 19 MeV. Two-thirds of these events were confidently associated with solar or geophysical sources. It was also shown that strong solar magnetic fields and interplanetary circumstances apparently significantly influence the propagation of energetic particles from the sun to the earth.

A study of the geomagnetic storms and solar flares in the years of increasing solar activity, cycles 19 and 20, has shown that of the 245 storms in the seven years studied, 62 percent were flare-associated, 30 percent were primarily sequential, and 8 percent remained unassociated. A preponderance of the storm-associated flares occurred in the western hemisphere of the sun, but the most severe storms were associated with flares strongly concentrated toward the central part of the solar disk.

HEAO-C Satellite Data: Part of the Space Physics Division program involves computing the effects of the geomagnetic field on the behavior of charged particles. The total problem has no general solution (that is, only special cases can be solved), and specific effects are obtainable only by detailed numerical calculations. The HEAO-C satellite, launched by NASA in 1979, provides an opportunity for an exact comparison of experimental measurements and theoretical calculations. The experiments on the HEAO-C satellite will observe cosmic ray heavy nuclei with hitherto unobtainable resolution. There is a phenomena, called the cosmic ray penumbra, that has been theoretically predicted for many years, but never actually measured because the measurement techniques were not sufficiently accurate and precise. This effect predicts that the geomagnetic field will "break up" the flux of high energy cosmic ray particles travelling through the geomagnetic field into fine details of allowed and forbidden energies. The in-house program involves computing the theoretical geomagnetic cutoff effects for the HEAO-C satellite orbit.

P78-1 Electrostatic Analyzers: Electrostatic analyzers designed to collect data on electrons in the auroral zones, particularly during magnetic storms and substorms, have been integrated into Air Force satellite P78-1. The results will be correlated with data from other sources and used to improve existing substorm models.

The experiment consists of four electrostatic analyzers looking in two different directions. They perform a differential energy analysis of electrons with energies from 50 eV to 20 keV, producing a 16-point spectrum for each look-direction every 256 msec. The detectors are mounted so that all pitch angles will be sampled with each revolution of the satellite.

The satellite is in a sun-synchronous polar circular orbit along the noon-midnight meridian. Since substorms occur most frequently and most intensely in this region, good substorm data should be acquired.

Interplanetary Scintillation Measurements: This study investigated the potential of interplanetary scintillation measurements to predict geomagnetic storms.

A number of USAF systems are sensitive to environmental perturbations associated with the phenomenon generally known as the "geomagnetic storm." The current techniques used to predict geomagnetic disturbances are not reliable for long-time predictions (of the order of days).

The solar disturbances that ultimately cause geomagnetic storms at the earth are essentially unpredictable. The solar initiated phenomenon (interplanetary shock wave) propagates from the sun to the earth in a time period that ranges from 1 to 4 days, depending on the type of disturbance. However, the phenomenon cannot be observed directly and its existence must be inferred from other measurements until it is actually observed by an interplanetary space vehicle or arrives at the earth. A new technique of monitoring the signals from discrete stellar radio sources shows promise of being a ground based remote probe of the interplanetary medium. Microscale (greater than 500 km) irregularities in the electron density component of the solar wind cause small angular diameter stellar radio sources to fluctuate, typically at a rate of about once per second. Variations which these interplanetary scintillations impress on the radio noise from stars may indicate turbulence in the solar wind and, hence, shocks propagating from the sun through the interplanetary medium.

The results of the study indicate that the interplanetary scintillation technique has the potential of predicting when solar initiated disturbances will intercept the earth and cause a geomagnetic storm.

Analysis of the available data indicates that at the 34 MHz frequency the peak activity precedes (on a statistical basis) maximum geomagnetic activity by 3.0 ± 1.7 days. However, the study also showed that other phenomena can result in enhancements in the interplanetary scintillations amplitude. For example, interplanetary scintillations are also correlated with solar wind density enhancements (which generally do not cause geomagnetic storms) as well as with turbulent plasma (which is associated with geomagnetic storms). One conclusion of this study is that whereas the interplanetary scintillation amplitude data can indicate a potential geomagnetic disturbance, the solar wind velocity (derived from another type of interplanetary scintillation data) is essential to predict when the turbulent plasma may intercept the earth and cause this geomagnetic disturbance.

LOW ENERGY PLASMA AND ELECTRIC FIELD STUDIES

Almost all Air Force communication and surveillance satellites must function within the earth's ionosphere-magnetosphere system, at altitudes from 200 km up to many earth radii. These systems need reliable and predictable RF propagation. However, the plasma in these regions, especially in the auroral and polar regions, is constantly changing.

The changes in the plasma are caused by a number of mechanisms. One important mechanism is the flow of energetic charged particles from the sun, the solar wind, which distorts the dipole configuration as the solar wind changes directly affect the morphology of the plasma in the ionosphere-magnetosphere region. The exact magnetic field configurations associated with changes in the plasma are not yet fully determined and one major effort of the investigation is to determine the electric and magnetic field fluctuations which are signatures of particular changes in plasma morphology.

One major impact on Air Force sytems caused by the plasma variations is the deviation and scattering of RF ray paths caused by large scale and small scale density gradients in the ionospheric thermal plasma. The prediction of these gradients and of the plasma density irregularities they may form is being studied by in situ satellite measurements of the plasma and ambient electric fields together with simultaneous ground based measurements. In recent years, the emphasis in this kind of study has partly shifted from the statistical study of a single parameter over an extended period to the study of individual events such as auroral substorms with the simultaneous measurement of many parameters.

High Altitude Electron Temperatures: In spite of the large number of spacecraft flown in the past twenty years, the altitude region from about 300 km up to about 10,000 km above the earth is relatively unexplored. Satellites with highly eccentric orbits pass rapidly through this altitude range and satellites investigating the neutral atmosphere and topside ionosphere are usually in orbits whose apogees are less than 300 km.

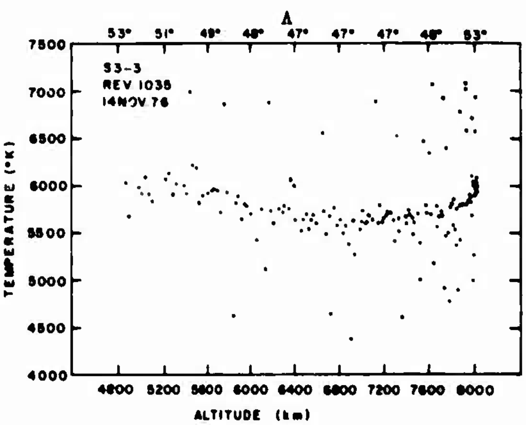
The Air Force S3-3 satellite, launched in July 1976 into a polar orbit, with a perigee below 300 km and initial apogee of 8000 km, has given an opportunity to carry out a systematic survey of thermal energy electrons up to 8000 km. Due to the low electron densities above about 3000 km (less than a thousand per cubic centimeter), the local-time coverage of this survey has been limited to within a few hours of the dawn-dusk meridian. When the orbit is in this local-time configuration, the electron sensor, which is mounted on a boom parallel with the spin axis, is in the shadow of the spacecraft. This eliminates the production of photoelectrons at the outer surfaces of the sensor and allows the measurement of ambient electrons down to densities of a few hundred per cubic centimeter.

Two distinct features of the thermal electrons in the 3000 km to 8000 km altitude range have been noted in these data. The first is that in the region of closed magnetic field lines (the "plasmasphere") there is little detectable change of electron temperature along a given field line as long as both ends of the lines are sunlit at approximately 300 km altitude. However, the temperature increases with increasing invariant latitude within the plasmasphere.

The second phenomenon noted is a sharp electron temperature gradient with values on the order of 0.4 degrees K per kilometer along the open magnetic field lines in auroral and polar regions. Since magnetic field lines are close to vertical throughout auroral and polar regions this field aligned electron temperature gradient has a vertical component.

Thus, despite the different magnetic field geometries in the plasmasphere and at higher latitudes, the observations show that in both regions electron temperature increases radially outward on the dayside of the earth in the 3000 km to 8000 km region. This implies a net downward flux of heat into the ionosphere, and since at least part of this heat flux is due to solar induced photoelectrons it forms a near constant contribution to the heat balance of the dayside ionosphere.

Ionospheric Plasma Trough: The ionospheric plasma trough is a major feature at middle latitudes and has been investigated since it was first identified in the mid 1960s. It occurs with varying frequency at all local times and all seasons. It can have a width of 2 to 20 degrees latitude, and within the trough the density of the ambient thermal plasma may be reduced by a factor of 50 or



Electron temperatures obtained from spherical gridded sensor flown on Air Force satellite S3-3. Values are close to 5700 K throughout the altitude range 4800 km to 8000 km along closed magnetic field lines.

more. Because of the ionospheric plasma density depletion in the trough, and because of the steep horizontal density gradients of its poleward and equatorward boundaries, radio signal propagation across the trough region is sometimes severely degraded as the morphology of the trough responds to solar-geophysical activity.

Measurements of trough occurrence frequence and morphology have been made using several thousand orbits of data from instruments designed by the Electrical Processes Branch and flown on the INJUN 5 and ISIS I NASA satellites. In addition to statistical information on trough width, depth and location, frequency of occurrence data for the full twenty-four hours of local time was determined for the first time. Previous studies have only indicated occasional observations of the trough on the dayside of the earth where solar UV produces sufficient local ionization in the topside ionosphere to mask the presence of a trough at altitudes below about 1500 km.

Two distinct troughs were frequently identified on the dayside above about 1500 km. One trough is located at approximately the location of the plasmasphere as is the trough observed at other local times. Within about three hours of local noon, however, a second trough is seen at high latitudes. It is this trough which has been reported previously from total ion density observations at low altitudes. It is located at the equatorward edge of the cusp region. This is the region on the dayside of the earth where the earth's magnetic field lines have direct access to the magnetopause. Energetic particles precipitating down the field lines from the magnetosphere cause the ionization which is observed as the poleward wall of the trough.

Satellite Electric Field Measurements: An electric field sensing system developed by the Electrical Processes Branch was flown on the Air Force S3-2 satellite and has provided several thousand orbits of good quality electric field data.

One specific study using this data, in combination with data from other AFGL instruments on this satellite, has been the identification in the ionosphere, close to the midlatitude trough, of very intense North-South electric fields with values as high as 280 mV/m. These fields are generally observed at times of auroral substorm activity and are located close to the current sheets associated with auroral arcs. The electric field region itself is located slightly equatorward of these current sheets, and very close to auroral optical emissions observed simultaneously.

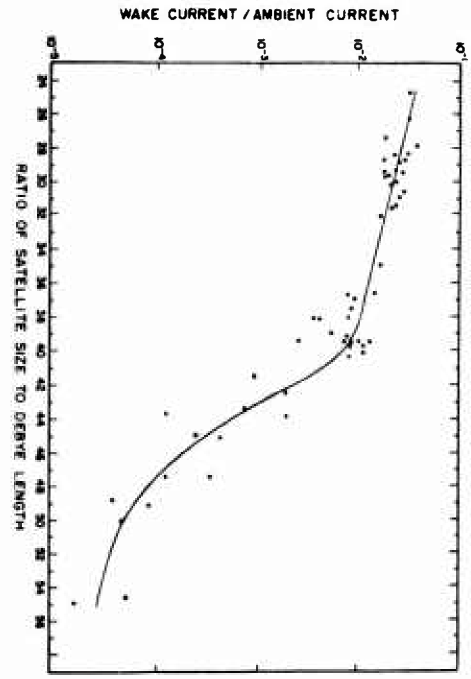
Spacecraft — Plasma Interaction: The interaction of a spacecraft with the ionosphere or magnetosphere plasma causes two classes of problems affecting both Air Force operational use of satellites and the acquisition of scientific data needed to better understand plasma phenomenology. As noted earlier, a combination of solar illumination, energetic particles and a low density ambient plasma can cause the generation of kilovolt potential differences between a satellite and its surroundings or between different parts of a satellite.

At altitudes below 1000 km, the charging problem is less severe but the higher ambient ion and electron densities cause a second class of problems affecting scientific measurements in particular.

This arises from the ion "sheath" which builds up around a conducting or partially conducting body immersed in a plasma. The sheath forms when positive ions are drawn toward the spacecraft which generally acquires a negative potential because of the high random thermal velocity of the electrons in the plasma. The ion sheath forms an electrostatic screen between the plasma and the negatively charged spacecraft to prevent further attraction of electrons. The exact resting voltage of the spacecraft and the dimensions of the ion sheath are functions of many parameters including spacecraft velocity and dimensions, and ion and electron densities and temperatures. The ion sheath greatly interferes with scientific measurements of the undisturbed ambient plasma especially when these are concerned with the thermal plasma where typical particle energies are on the order of a few electron volts at most. This is frequently less than the potentials acquired by the spacecraft. This interaction between the spacecraft and its surroundings can also generate wave phenomena in the ambient plasma.

The geometry and electrical characteristics of the sheath have been studied in the past mainly with the object of determining its effect on data from scientific sensors on a specific satellite. To do this, many simplifying assumptions were made. A rigorous model of the interaction between a shaped conducting body and the ionosphere-magnetosphere plasma does not yet exist. In the Space Shuttle era, however, structures will be assembled, initially in the 100 km to 500 km altitude range, which will be significantly larger than present spacecraft. They will have dimensions on the order of one hundred meters or more, and a quantitative description of the interaction between such a structure and the plasma is urgently needed. Until such a model is produced, it is probable that problems due to current flows within structures, RF interference, and electrical discharges between docking spacecraft will impede steady progress toward the establishment of operational space structures during the shuttle era through the mid-1990s.

A simplified study of sheath structure was carried out using data from the ion and electron sensors built by the Electrical Processes Branch and flown on the Air Force S3-2 satellite. The data used consisted of thermal electron density and temperature, and spacecraft potential, all obtained from a spherical gridded sensor mounted on a 1.2 meter boom parallel with the spacecraft spin axis, together with positive ion currents flowing to two arrays of planar aperture ion sensors mounted on the surface of the satellite. Once during each 20-second spacecraft rotation each of the ion sensors faced into the "ram" direction, and the ion current measured at this time was taken as proportional to the ambient ion density. One-half rotation later, the current is a measure of the depletion of positive ions



Comparison of the ratio of satellite wake to ambient currents and the ratio of satellite size to Debye length. The wake current decreases relative to the ambient current when the satellite size is greater than approximately 40 times the Debye length.

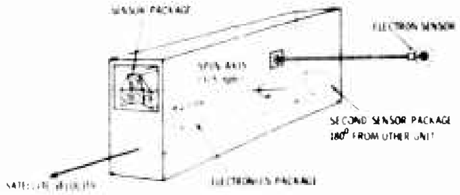
caused by the passage of the satellite through the plasma.

The ratio of wake to ambient currents was taken as an indication of the relative disturbances to the plasma caused by the satellite. This ratio was determined over a range of values of three parameters. These were: the spacecraft potential with respect to the plasma; the relative velocity of the spacecraft compared to the mean ion thermal velocity, and the ratio of the major dimension of the satellite to the Debye "screening" length of the ambient plasma, which is a function of electron temperature and plasma density.

No significant correlation was found in the data set between the current ratios and spacecraft potential. Although some change was noted as the ion mean thermal velocity increased, the major dependence, at least in the data available for this study, is with the ratio of satellite size to Debye length. In practice, this means that the relative depletion of positive ions in the wake of a spacecraft decreases as the Debye length increases. In the ionosphere for a satellite with dimensions of a few meters this will occur at about 500 km altitude. Together with the absence of correlation of ion and wake currents with spacecraft potential and the slight effect noted with changes in mean ion thermal velocity, this means that the electrical conditions near the surface of a spacecraft are determined largely by the relation of its dimensions to the local plasma Debye length.

S3-2 Satellite Data: Data from the S3-2 satellite are being utilized to study the near earth space environment in the polar regions, regions subject to intense current systems, standing shock waves, strong current streams, and magnetic substorms. Geophysical conditions in this region can vary drastically both with time and distance. Approximately 18 months of data from the S3-2 satellite have been digitized while selected events were concurrently analyzed.

On 11 January 1976 the Air Force satellite S3-2 passed over the auroral oval within ten minutes of the DMSP passage over the same regions, thus allowing a comparison between the DMSP picture of the auroral oval with the near-coincident S3-2 measurements of electron flux, thermal plasmas, plasma bulk motions, magnetic fields and electric fields. The continuous aurora (towards the equator) occurred in the region of downward field-aligned currents, with a low intensity of electron flux; discrete auroral arcs occurred in the region of upward field-aligned currents (with the brightest arc toward the poleward edge) where the electron flux reached a value as high as 10^{9} electrons/cm^2-sec-ster. From analysis of the bulk plasma flow, AFGL scientists determined that the downward current was carried by thermal electrons and the upward current by precipitating electrons. The electric field was northward directed over the regions of current except near the most intense currents at the visible area. In this region there are indictions of a component of the electric field parallel to the magnetic field where the current is downward, and anti-parallel where the current is upward.



S3-2 satellite experiment locations. The gridded electron sensor, at the end of a 1.2-meter boom, measured electron density, electron temperature, and spacecraft potential. The planar sensor packages on the spacecraft surface measured positive ion currents. The spin axis of the satellite is also shown.

SPACECRAFT CHARGING TECHNOLOGY

Many Air Force communications satellites are in geosynchronous orbit for maximum efficiency. At the altitude of geosynchronous satellites (about 26,000 miles or 6.6 earth radii), the earth's space environment electrically charges some of these satellites and can degrade their performance.

The problem which the Spacecraft Charging Technology Project addresses is to understand the complex interaction between a satellite and the plasma environment at geosynchronous orbit.

During a magnetospheric substorm, a satellite wrapped in its thermal insulation blanket is essentially a capacitor immersed in a high temperature plasma. Secondary emission, photoelectron emission, and the ambient thermal plasma all contribute to the satellite's net potential. Anisotropies in the satellite's plasma sheath, created by spin, velocity, and shadowing, complicate the interaction and influence the charge balance. Shadowing of the spacecraft allows a high negative potential on the dark side of the spacecraft, while on the sunlit side, the potential is near zero. When sufficient voltages occur, current discharges which produce electromagnetic interference can follow. The electromagnetic interference can cause circuit upset or satellite failure.

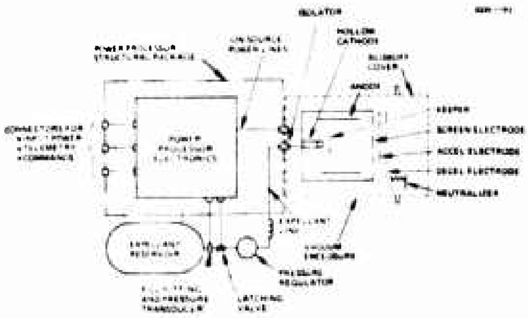
The importance of spacecraft charging effects on satellite performance was only recently recognized. An interdependent Air Force Systems Command (AFSC) and National Aeronautics and Space Administration (NASA) space technology program was formed to investigate spacecraft charging. AFGL's Spacecraft Charging Technology Project is a key element of this interdependent AFSC/NASA technology program. In the project, we model the spacecraft charging phenomena, define the geosynchronous plasma environment, and develop techniques for active control of satellite potential. The technology base derived from these efforts is immediately applicable to continuing and planned Air Force space systems. The goal is to support SAMSO (Space and Missile Systems Organization) in developing a satellite test specification and a design criteria for spacecraft charging.

SCATHA: The SCATHA (*S*pacecraft *C*harging *at* *H*igh *A*ltitudes) satellite is an integrated satellite experiment that is used to measure the characteristics of the spacecraft charging phenomena, to determine the response of the satellite to the charging process, and to evaluate corrective techniques. The SCATHA satellite was launched from the Eastern Test Range in January 1979. SCATHA has an equatorial orbit with an apogee of 7.7 earth radii and a perigee of 5.5 earth radii.

The 13 experiments on SCATHA are provided by AF, Navy, NASA, DNA, industry and university groups. There are engineering experiments to measure surface potentials and the electrical effects of spacecraft charging on satellite surface and subsystems. Environmental experiments measure the characteristic fields and particle fluxes. Two of the AFGL experiments fall into this latter group, the Thermal Plasma Analyzer and Rapid Scan Particle Detector. AFGL also provided an electron beam system and a positive ion beam system. These systems will be used to develop techniques to actively control spacecraft charging. The engineering, environmental and charge control experiments were selected to work in concert and, thus, relate cause and effect in spacecraft charging.

Ion and Electron Beam Emitters: The study of spacecraft charging requires the ability to control as many of the variables as possible. One way to do this is to charge the vehicle artificially, at a known rate. To do this, AFGL has developed two experiment packages for the SCATHA satellite.

The Satellite Electron Beam System is an electron beam source, and the associated electronics for controlling and measuring the emitted current. Under ground control, the current and energy of the emerging electron beam may be varied to produce a range of positive spacecraft charge.



SCATHA Satellite Positive Ion Beam System.

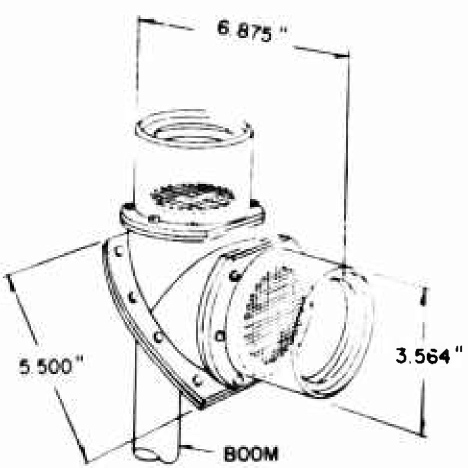
To investigate the effects of positive charge emission, the Satellite Positive Ion Beam System was developed and incorporated into the satellite. Capable of emitting either electrons or positive ions or both, this payload uses non-contaminating xenon gas to produce a wide dynamic range of useful charging rates and energies.

The two packages together provide the ability to charge the satellite to a positive or negative potential, to discharge the charged satellite, and to hold the satellite in an uncharged condition.

Rapid Scan Particle Detector: The Rapid Scan Particle Detector measures the flux of electrons and ions incident to the spacecraft in directions perpendicular and parallel to the spin axis of the satellite. These measurements enable researchers to determine the number, density, temperature, and bulk flow of the plasma and the relationship of these quantities to the occurrence of spacecraft charging. In addition, the Detector is used to monitor the response of this plasma to the operation of the Electron and Positive Ion Beam System and to provide a synoptic survey of the plasma characteristics as a function of local time, altitude, and geomagnetic conditions.

Space Environment Specifications: AFGL has undertaken an ambitious program having as its ultimate goal the specification of ambient space environment in which military operations take place. As the first phase of this effort, a preliminary, but detailed, specification of the geosynchronous environment has been prepared for inclusion in the Military Standard on Spacecraft Charging. In conjunction with this specification, a simple analytic model capable of predicting the status of the geosynchronous environment was developed and incorporated into the GWC and NOAA/SELDADS systems. It is planned to update and further define these results with data from the SCATHA satellite in 1979 and 1980. Comprehensive models are also being developed of the near-earth and polar regimes as these are also regions of potential impact on military systems.

Computer Modeling: A theoretical description of the process of spacecraft charging by magnetospheric substorm plasmas is being prepared in the form of a computer code called SCATHCAP (SCATHA Charging Analyzer Program). The SCATHCAP code performs a dynamic, fully three-dimensional simulation of electrostatic charging processes for an object in space or in a ground test chamber environment. In particular, the code predicts surface potentials on spacecraft, identifies high-field areas of possible discharge sites, predicts response to environmental change, predicts and interprets particle detector response and assesses the effects of particle emission from active control devices. In the code, the spacecraft is represented by a finite element method, each element being a cube or a slice of a cube. The computations are performed in nested meshes, with an inner mesh size of 16 x 16 x 32 cells. Each successive mesh has double the mesh spacing, and as many as seven meshes have been employed. A different material may be specified for each element surface, so that properties such as secondary emission, backscattering, photoemission and conductivity may be taken into account for each cell. The surface resolution of spacecraft



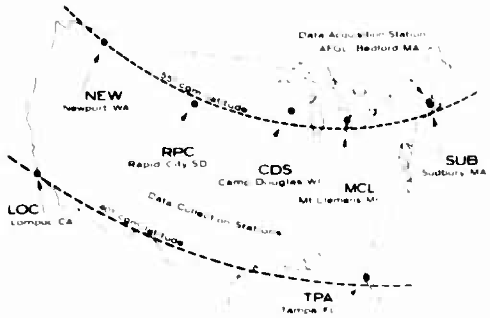
The thermal energy positive ion and electron sensors, mounted at the end of the 3-meter boom which projects in the spin plane of the spacecraft.

detail is about 10 cm. The code calculates particle trajectories in sheath fields as well. The SCATHCAP code is the most advanced satellite charging code available and will be extensively employed for the analysis of spacecraft charging and active control of future satellite systems, for studies of contamination, and for the analysis of the response of particle detectors on spacecraft.

THE AFGL MAGNETOMETER NETWORK

AFGL's network of magnetometer stations, which extends across the continental United States, monitors the earth's magnetic field continuously. Each instrumented data collection station operates continuously and automatically, unattended except for routine maintenance. Data from each station are returned in real time on commercial voice-grade communication circuits to a single data acquisition station located at Hanscom AFB, Massachusetts. The data acquisition station processes, reduces, and displays the data in real time, and stores processed data in a permanent file for subsequent analysis. All the facilities are dedicated to the program, so essentially uninterrupted operation over an extended time period is possible.

The magnetometer network has several important features. The geographic distribution of stations makes it possible to obtain a detailed picture of the magnetospheric currents which cause magnetic disturbances. The synchronization of stations and the rapid sampling rate permit high time resolution measurement of both strength and direction of the earth's magnetic field. Identical instruments at each station produce directly comparable data. The ability of the stations to operate without interruption for several years allows continuous monitoring of the magnetic field. The automatic real time processing, storage, reduction, and display of the combined data allow operational units to make use of the information. Finally, the network can be



Geographical locations of the stations in the AFGL magnetometer network.

expanded or operated in conjunction with networks established by other organizations.

The network now includes seven stations. Five are spaced across the northern United States at about 55 degrees N corrected geomagnetic latitude, while two others space the southern United States at about 40 degrees N corrected geomagnetic latitude. The principal instruments at each data collection station are triaxial fluxgate and searchcoil magnetometers. The sites are provided with electrical power, a voice-grade communications line for data transmission, and telephone service.

The data-conditioning circuitry at each data collection station accepts instrument data and converts them to a signal which can be transmitted by the data communications link. The process includes sampling of output data, converting to digital form, ordering into a standard frame format, coding for error-rate improvement, and outputting as a serial bit stream. A microprocessor with a stored program controls all of these functions.

The data acquisition station has two principal functions: network control and data processing. Network control is accomplished through the generation of a network-control signal which is transmitted continuously on the outlink of the data communications link. The inlink is used for data return, time-shared by all of the data collection stations, each of which transmits a frame of digitized data in a programmed sequence. Each data collection station responds according to instructions contained in the signal, which synchronizes the taking of data samples by the scientific instruments and the transmission of these data at the proper time.

An excellent data base for the year 1978 has been archived, and fulltime operation is continuing. The full complement of seven stations was completed in late 1977, but data archiving began in 1976. The data are now sufficient to support intensive efforts in analysis and scientific study.

Two objectives of the network are the specification and prediction of the state of the magnetosphere and the understanding of magnetospheric processes, particularly as these affect the performance of military systems which must operate in the space environment at the base of the magnetosphere. Since the interior field of the earth is constant, the surface field measured by the network is a direct reflection of magnetospheric processes. The wide geographic coverage affords part of the three-dimensional view needed to discover the sources and propagation directions of disturbances. The use of simultaneous spacecraft measurements in conjunction with the network data provides an even more powerful method for attacking major problems in the magnetosphere.

Several problems are now being studied. Sudden commencements, which result from compression of the magnetosphere by a shock wave from a solar flare, are usually precursors to magnetic storms and can serve in the prediction of the space environment; the network data permit these to be detected in real time, and their propagation near the earth can be studied in detail. Geomagnetic pulsations reflect specific processes occurring at distant locations; for example, the onset of substorms is accompanied by the Pi2 type, which can therefore serve as another prediction indicator. An overall activity index can be determined in real time from the network data, so a realtime knowledge of the condition of the magnetosphere is possible. To aid in these studies, a variety of analytical techniques has been developed; among these are bandpass filtering, nonlinear maximum-entropy power-spectral analysis, and computer-generated plots of the data and reduced parameters.

IONOSPHERIC DYNAMICS

Two regions of the global ionosphere routinely exhibit a disturbed character: the high latitude ionosphere, poleward of approximately 55 degrees corrected geomagnetic latitude and the equatorial ionosphere, equatorward of approximately 20 degrees geomagnetic latitude.

These regions are characterized by the routine occurrence of ionospheric irregularities, strong horizontal electron density gradients, and rapid changes in the horizontal and vertical electron density distributions. These phenomena arise from a variety of sources, such as ionospheric currents, ionospheric and magnetospheric electric fields, neutral air motion and energetic particle precipitation at high latitudes.

The disturbed ionospheric regions affect radio wave propagation over a large part of the radio frequency spectrum, from very low frequencies (3 to 30 kHz) to super high frequencies (3 to 30 GHz). Many Department of Defense communication and surveillance systems operate in or through these disturbed regions.

The Space Physics Division uses a unique tool in the investigation of the disturbed ionosphere and its impact on Air Force systems: an NKC-135 jet aircraft, the Airborne Ionospheric Observatory, instrumented for auroral and ionospheric research. The instrumentation consists of sophisticated ionospheric sounders, receivers covering a large part of the radio wave spectrum, photometers, spectrometers, all-sky cameras and an all-sky photometer. This combination of experiments is the basis for many studies that describe in detail the environment and the environmental effects on Air Force systems.

Equatorial studies, centered around the aircraft and the all-sky photometer, reveal a dynamic and structured equatorial airglow pattern. The airglow features identify the site of ionospheric irregularities that cause scintillations on satellite communications links.

The optical response of the atmosphere to the particle precipitation at high latitudes is the aurora. The understanding of the coupling of ionospheric, magnetospheric and auroral phenomena has progressed considerably over the last decades, and auroral measurements by the Airborne Ionospheric Observatory have been instrumental in achieving this increased understanding of the high-latitude ionosphere and its impact on Air Force systems. This understanding is being used to assist in specifying the environmental impact on the operation of the evolving CONUS Over-the-Horizon Backscatter Radar System.

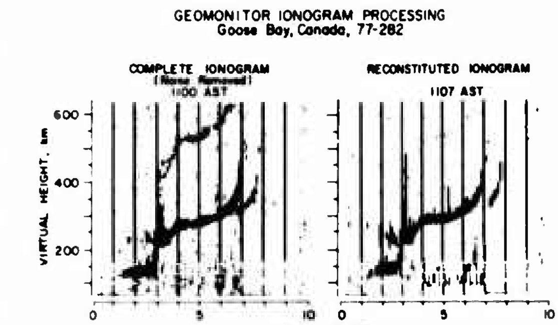
Quantitative studies are closely aligned with the experimental investigations. These studies involve theoretical modeling of the E-layer electron density profiles and work to derive ionospheric parameters from aurora and airglow emissions. These latter efforts are directed toward large-area ionospheric mapping by optical techniques.

To enhance the results from the limited number of airborne studies, continuous observations of the high-latitude ionosphere are conducted at the Goose Bay Ionospheric Observatory. These observations are used to develop remote sensing techniques to provide a routine input into the Air Weather Service Space Environmental Support System and to permit the classification of specific airborne measurements with respect to the general behavior of the ionosphere.

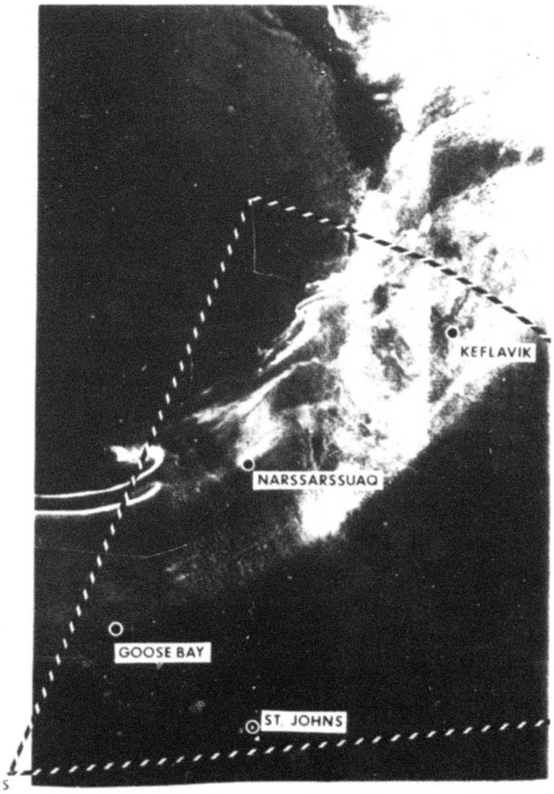
GOOSE BAY IONOSPHERIC OBSERVATORY

The AFGL Goose Bay Ionospheric Observatory (GBIO) plays a significant role in defining the effects of the high latitude ionospheric environment on defense systems while also contributing to Air Force operations. Located at 65 degrees corrected geomagnetic latitude, GBIO has a geophysically significant location; during nighttime, it is in the proximity of major high latitude ionospheric features such as the auroral E-layer, the F-layer poleward trough wall, the equatorial boundary of the auroral ionosphere, and areas of ionospheric irregularities and auroral absorption. These features have large latitudinal gradients and distinct boundaries while extending over hours of corrected geomagnetic local time. The location is suitable for gathering research data on these ionospheric disturbances and the motions of the ionospheric boundaries.

GBIO contributes to Air Force operations by the acquistion and processing of ionosonde, magnetometer, riometer, total electron content, and radio beacon scintillation data and the communication of the results to the Air Force Global Weather Cen-



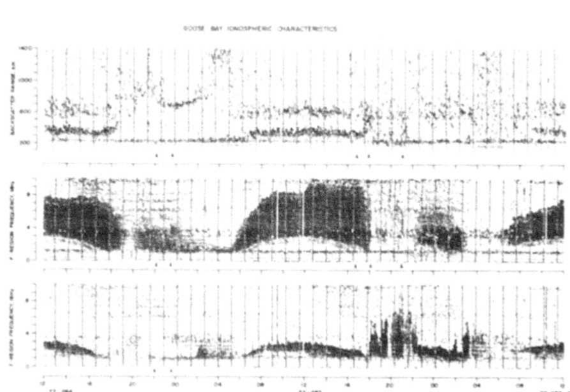
On the left is a complete digital ionogram, representing 21,600 6-bit characters. On the right is a 2,340 character reconstituted ionogram.



This Defense Meteorological Support Program satellite image of the aurora is a dramatic example of the relationship of the night sector of the auroral oval under very disturbed conditions and the experimental Over-the-Horizon Radar coverage zone.

tral in real time. The 414L Over-the-Horizon radar system is an ionospherically dependent defense system needing data from locations such as GBIO. Goose Bay vertical incidence ionograms will be displayed in real time at the Experimental Radar Site in Maine during the System Performance Test. The Goose Bay ionograms are important for understanding the performance of the system. GBIO data will also be used for the subsequent ionospheric specification performed by AFGL and the Air Weather Service for the Over-the-Horizon Radar System Program Office.

Geomonitor: In the past, AFGL has participated in the development of advanced ionosondes using digital instead of analog formats which extend the capability of this research tool to operational use. The digital format permits real time, automated processing but the volume of data is significant. Digital techniques for echo recognition have been developed which reduce the data volume (from 21,600 to 2,340 characters per ionogram), prepare the ionospheric data for further processing, and simplify data storage and transmission. Analytical methods perform detection of the echoes and the determination of their virtual height, amplitude, and range spread. For real time application, these techniques have been implemented, using a microprocessor, in the Geomonitor, now in operation at GBIO. The echo detection algorithm detects up to six echoes, two from the E-region below 156 km and four from the F-region above 156 km. Echo verification and accurate virtual height measurement are accomplished by comparison with a sliding standard pulse. The spread, or apparent width in virtual height, is also determined for the largest E- and F-layer echo.



Forty-eight hours of characteristics from the Geomonitor at the Goose Bay Ionospheric Observatory. The top panel shows the integrated range display from the poleward directed backscatter ionosonde. The echo amplitudes are normalized for each of 128 height intervals. The middle panel shows the vertical incidence F-region frequency characteristics while the lower panel shows the E-region characteristics. Frequency characteristics are created by printing the largest echo amplitude for all frequencies in each region.

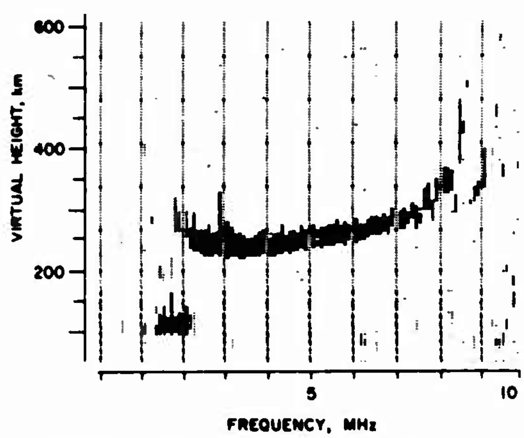
The detected echoes can be recast into the format of the original digital ionogram for use at a central user site after transmission from the remote observing site. These reconstituted ionograms are also created by the Geomonitor at the observing site for verification of proper performance. Almost all of the detail of the complete ionogram is retained in the reconstituted ionogram, adequate for operational monitoring.

Space Data Communication: Presently, observers acquire Space Environmental Support System data, process it, and report it to the Air Force Global Weather Central. An automated system could take data 24 hours each day at a fraction of the cost of observers working 8 hours each day. The Geomonitor presently operational at the Goose Bay Ionospheric Observatory acquires magnetometer, riometer, radio polarimeter, and satellite radio beacon data and performs rudimentary processing on it. However, the capabilities of the Geomonitor cannot be expanded to include the automated acquisition, processing, and communication of data desired. Furthermore, the Geomonitor was designed for real-time analysis of data from the digital ionosonde at Goose Bay Ionospheric Observatory, while digitizing other types of data.

Therefore, work has begun on designing a Space Environmental Support System Data Communicator which will use existing data message formats and communications circuits, and which will be retrofitted to existing analog sensor systems. The prototype is expected to be a versatile, micro- or mini-computer based system using standard modules assembled to automatically acquire whatever data is taken at the particular site, process it and communicate it to Air Force Global Weather Central over standard teletype circuits.

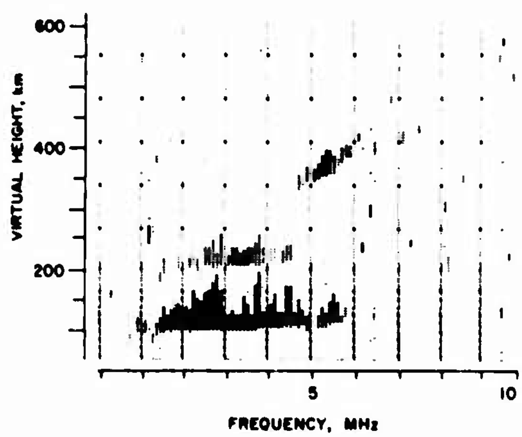
The data would be recorded as well as transmitted, to expand the research data base, and allow quality control. The system should be able to automatically answer a call from the Space Environmental Support System Duty Forecaster at Air Force Global Weather Central, who could interact with the system as though he were at the data collection site.

77-287, 1637 AST



An example of how characteristics and reconstituted ionograms could be used in an Over-the-Horizon radar. The upper picture shows a late afternoon midlatitude ionosphere with f_oF_2 of 8.7 MHz. Radar operation near Goose Bay would be by F-layer propagation. However, the backscatter range characteristic has recorded the approach of echo-producing ionospheric features. Below, the reconstituted ionogram at 6 p.m., after the arrival of the echo-producing disturbance. Operation near Goose Bay would now be by E-layer propagation. The reconstituted ionograms show the radar site what the ionosphere near Goose Bay is like while the characteristics give warning of the approach of a disturbance.

77-287, 1800 AST



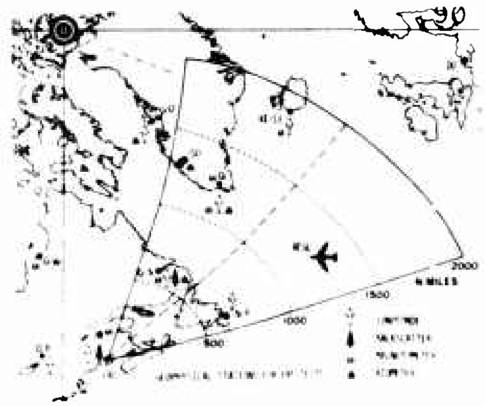
Airborne Studies: The AFGL Airborne Ionospheric Observatory has the unique advantage as an auroral observing system of being able to fly westward so as to dwell continuously at a fixed local magnetic time for as long as 10 hours. Thus, it can observe local midnight in the frame of reference of the magnetosphere-ionosphere itself, uncomplicated by the passage of local time.

A number of such case studies have been performed, the most extensive of which was a 12 hour period which included two isolated substorms. For nine of the 12 hours, the AFGL Airborne Ionospheric Observatory flew so as to remain constantly near local midnight, a path which also intersected four consecutive passes of the ISIS-2 sateilite and the fields of view for eight passes of DMSP satellites. The simultaneous and complementary ionospheric, photometric, photographic, magnetic and particle measurements have been used to map and interrelate the auroral E- and F-regions, the electrojet, and the discrete aurora in the oval and polar cap. Where possible, phenomena which are caused by a particular type of precipitating particle were identified. The results were detailed in four papers.

Discrete Auroras Near Midnight: The discrete aurora produces sporadic E phenomena which interfere with HF propagation, HF communications, and OTH-B surveillance. In addition, the optical emissions from the discrete aurora interfere with certain optical surveillance systems.

The discrete aurora has been studied using all-sky camera photographs taken on 12 extended local midnight flights by the Airborne Ionospheric Observatory. Photographs were taken at 1 minute intervals during the total of 93 hours with continuous coverage per flight ranging from 5 to 9.75 hours.

A characteristic lifetime of auroral occurrence has been defined by this study as 15 minutes. The significance of this lifetime is that it is the same as the characteristic duration of plasma flows measured in the plasma sheet by satellite. These flows are further believed to produce electrostatic shock waves which accelerate electrons to keV energies, appropriate to produce the discrete aurora. Apparently, then, the auroral lifetimes are related to the duration of these flows.



Geophysical stations supporting the Experimental Radar System tests.

Aurora and Auroral E-Layer: The other important result was the further definition of the continuous (or diffuse) aurora and of the auroral E-layer which it produces. Earlier work had shown that this aurora exists at all local times, is always present, is the only aurora in very quiet times, and represents most of the energy input into the auroral ionosphere.

This present work has shown that it forms a better basis for the positional ordering of auroral phenomena than the Feldstein oval since the continuous aurora defines the position of most of the auroral phenomena in the night sector: the discrete aurora is poleward or overlaps the poleward edge of the continuous aurora; the F-layer irregularity zone coincides with it; the F-layer trough wall is below the equatorward edge; and the region of D-region ionization overlaps the equatorward edge.

Auroral E-Region Program: The purpose of this program is to study the feasibility of sensing electron density profiles for the continuous (or diffuse) aurora by satellite measurements of optical emissions. The program consists of coordinated rocket, satellite, aircraft and ground-based measurements, and a theoretical effort to analyze the data.

The experimental program is planned for the winter of 1980-81 at Poker Flat, Alaska, and consists of the following measurements: electron and proton energy spectra by satellite and rocket; volume emission rates by selected wavelengths by rocket; electron, ion and neutral particle densities by rocket; electron and neutral particle temperatures by rocket; electric and possibly magnetic fields by rocket; electron densities by the Chatanika incoherent scatter radar; and other ionospheric, geomagnetic, photographic and photometric quantities by the Airborne Ionospheric Observatory and ground facilities.

The theoretical program consists of the application of the methods of transport theory to calculate most of the experimentally-determined quantities. Experiment and theory can then be compared, and the feasibility of determining electron density profiles for the auroral E-layer from satellite optical measurements assessed.

High Latitude Auroral Imaging: An All-Sky Imaging Photometer, developed under a Laboratory Director's Fund Program, has been installed in the Airborne Ionospheric Observatory. This instrument provides a new capability to monitor auroral emissions of importance to ionospheric and magnetospheric processes. Several flights in the evening/midnight sector of the auroral oval have been completed. Studies are in progress to relate ground backscatter echoes from the Goose Bay Ionospheric Observatory to optical auroral features in an effort to correctly interpret the backscatter measurements, and thus improve remote monitoring of auroral oval dynamics. Extended flights in the noon sector have provided the first spectral images of the dayside (cleft) aurora. The dynamics of the dayside aurora are being investigated to establish their relation to auroral substorms and Interplanetary Magnetic Field (IMF) variations.

Photoelectron Flux and Optical Emissions: These studies seek to determine to what extent altitude profiles of electron and neutral densities can be determined by remote satellite sensing of optical emissions.

At the request of SAMSO, AFGL has undertaken a program in the remote sensing of daytime electron and neutral density altitude profiles at midlatitudes from satellite optical measurements. To do this, a sufficiently accurate theory for the photoelectron flux is needed; once it is known, volume emission rates at selected wavelengths may easily be calculated. Satellite optical emission measurements can then be used to determine altitude profile information.

At AFGL, a new approach (combining the Boltzmann and Fokker-Planck equations) was used to calculate the photoelectron flux for the daytime, bottomside ionosphere. The self-consistent solution of the combined equation led to improved agreement between theory and experiment for the photoelectron flux at electron energies ranging from 1 to 60 eV.

In the future, these methods will be generalized so that properties of the topside ionosphere that are of interest to SAMSO and the AWS can be studied.

SIGNAL SCINTILLATIONS

Irregularities in electron density in the ionosphere produce both phase and amplitude fluctuations of signals passing from satellites to ground or vice versa. The problems occur at high latitudes and in the region within 20 degrees of the magnetic equator.

Frequencies from 20 MHz to 6 GHz have been affected. The study of scintillations as a function of latitude and longitude, time of day, magnetic conditions, and solar conditions, allows operational systems to realistically confront the natural problems they encounter. The development of models of both the short-term and long-term behavior of these irregularities allows engineers to develop second generation systems which will keep the problems caused by fading to a minimum.

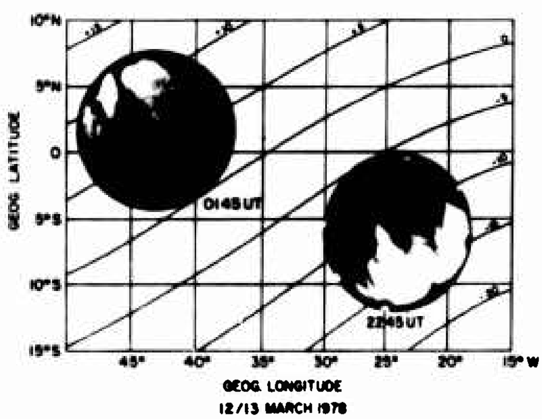
During the past few years, AFGL researchers have concentrated on the equatorial irregularity structure since it produces considerably greater effects. It has been established that the nighttime ionospheric equatorial irregularity regions emerging after sunset develop from bottomside instabilities. A bubble depleted in electrons rises from below the peak of the F_2 layer (below 250 km) into altitudes ranging to 1000 km. Propagation of satellite signals through these bubbles leads to severe amplitude and phase fluctuations. The bubble formation has been studied by a variety of methods.

For the systems designer, the patch development, size, duration, and decay properties are important. Three campaigns, each lasting about two weeks, were mounted, one each in October 1976, March 1977, and March 1978, to investigate equatorial irregularities and their effects on satellite communication links. Airborne and ground-based instruments were used in these campaigns. Instruments designed for geophysical experiments significantly enhanced the scintillation studies.

An all-sky imaging photometer monitored structures in the 6300 angstrom airglow emission (airglow depletions). These airglow depletions are the optical signatures of regions of low density plasma which contain the irregularities responsible for the plume type echoes received by the 50 MHz Jicamarca Backscatter Radar, for spread F echoes in ionosondes, and for UHF and VHF scintillation. The horizontal extent of these regions can be mapped optically, complementing other diagnostic techniques. Scintillation measurements of satellite signals were carried out from Ancon and Huancayo, Peru, from Natal, Brazil, and from Ascension Island, as well as from the Airborne Ionospheric Observatory.

A model of the equatorial irregularity patch emerged. The patch is a region of low electron density containing irregularities with scale sizes ranging from three meters to tens of kilometers. These structures measure 100-200 km east-west, over 2000 km north-south across the magnetic equator, and extend in altitude from 200 km to 800 km. They form after sunset, and then move eastward with velocities ranging from 100-200 meters per second, slowing down towards midnight and dissipating in the morning hours. This eastward motion of the irregularities causes a very clear dependence of the signal fading rate on the aircraft heading. Since the drift direction is well established, the ratio of the fading rates for easterly and westerly courses permits an estimate of the drift velocity of the irregularities. Patches have been tracked by the aircraft and through ground measurements for over 3 hours. The irregularity structure and its drift velocity appear stable enough over this time span so that the full heading dependence can be mapped.

These banana-like patches usually end within 20 degrees of the geomagnetic equator. Irregularities over the equator at



Images of the 6300 Å airglow taken north and south of the magnetic equator during the night of March 17-18, 1978.

600 km map to 200 km altitude in the path from Ascension Island to a synchronous satellite. The entry point is about 13 degrees from the magnetic equator. When the

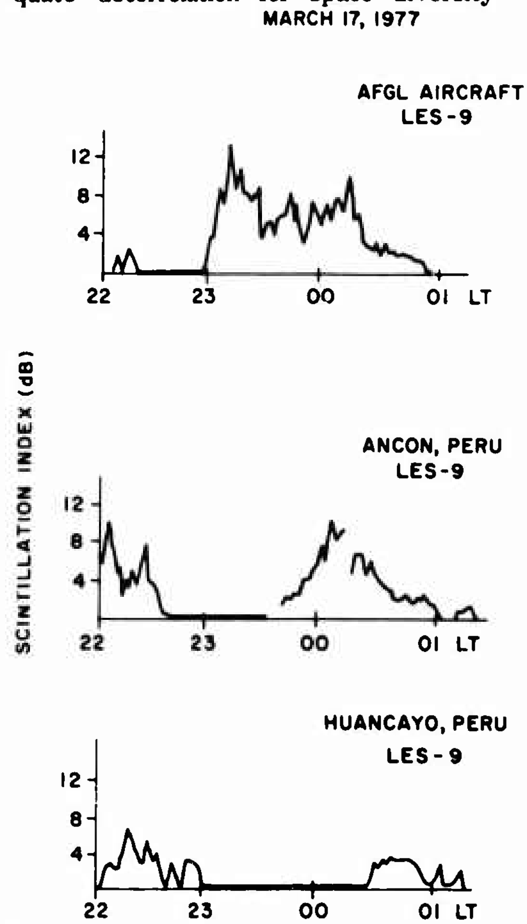
irregularities come into the lower F-region, they terminate (the tip of the banana). If the irregularity extends to altitudes greater than 600 km at the equator, the irregularity may extend to higher altitudes and latitudes away from the equator.

Signal Statistics of Equatorial Scintillations: The October 1976, March 1977, and March 1978 equatorial campaigns provided many periods of intense scintillations from the Ancon, Peru, station. These have been analyzed for signal statistics, i.e., the S_4 index, auto-correlation function and power spectra. In addition, spaced receiver data were processed to determine the velocity of the irregularity regions from the spatial correlation function. Signal statistics as a function of time were correlated with the passage of irregularity regions through the Jicamarca radar. On a typical evening, shortly after sunset, the S_4 index, which measures the intensity of scintillations, shows an abrupt rise at the onset of scintillations and its variations trace the passage of one or more irregularity regions through the antenna beam. The index often reaches or slightly exceeds unity indicating the development of a Rayleigh fading distribution, a characteristic of the most intense scintillations.

The autocorrelation interval is a measure of the bandwidth or rate of scintillation. The autocorrelation interval was usually low, of the order of a few tenths of a second, following the onset of scintillations, but could rapidly rise to a value of several seconds. Generally, the autocorrelation interval was lowest during the most intense scintillations.

Diversity schemes can reduce the effects of fading during a scintillation event by combining two signals that are fading independently. Most of the diversity improvement is obtained for correlation coefficients less than 0.6 when slow multiplicative Rayleigh fading occurs and equal signal-to-noise ratios occur in both branches of a dual diversity system. The autocorrelation data indicates that time diversity techniques would have to provide delays of a few seconds to significantly reduce the effects of scintillation.

Cross correlation data from spaced receivers on an east-west baseline of 366 meters showed great variability under conditions of intense scintillations, ranging from a low of 0.2 (almost complete decorrelation) to almost unity. A much larger spacing would be required to provide adequate decorrelation for space diversity under all conditions of intense equatorial scintillations.



Tracking an irregularity patch by noting scintillations. The patch moves past several points.

The velocity of the irregularity regions was also determined from the spaced receiver data by measuring the time delay. The irregularities move eastward with speeds that typically vary from approximately 50 to 200 meters per second.

The studies are continuing with emphasis on the variation of signal statistics as the irregularity patches evolve and decay.

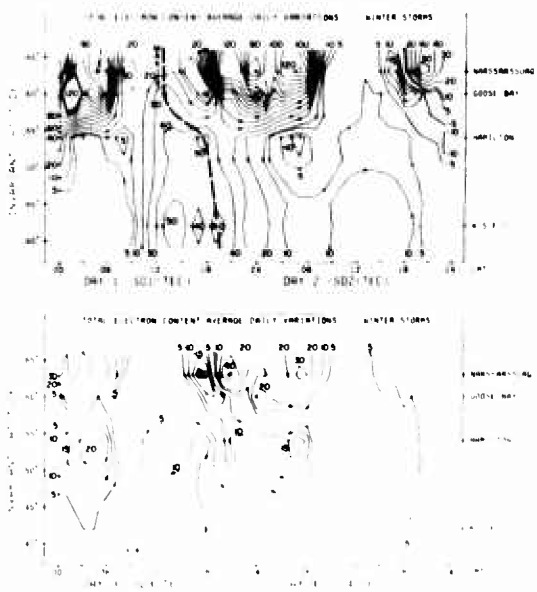
Auroral Effects: Airborne ionospheric and auroral observations have been combined with simultaneous scintillation measurements from polar orbiting satellites. This technique proved successful in mapping irregularities over large sections of the polar region for extended periods, and for correlating scintillations with auroral or ionospheric structures.

A high latitude model of scintillation activity has been completed. The model is limited to providing scintillation fluctuations over the range of invariant latitudes of 53-64 degrees. It uses long-term data extending from 2½ to 6 years. In the model, scintillations depend on time of day, day of the year, solar flux, invariant latitude, and magnetic index. Frequency dependence terms and geometrical corrections have been added to the model. Data on polar latitudes is still sparse so that a polar term could not be developed. Future observations over Thule are expected to add data to complete this study.

IONOSPHERIC CORRECTIONS FOR PRECISION RADARS

Refraction of radio waves in the normal ionosphere, particularly at solar maximum, degrades the measurement of precise range and bearing. For modern tracking radars, such as COBRA DANE and PAVE PAWS, refraction effects create errors that exceed the required metric accuracy; therefore, a correction must be made in real time for each radar hit. Analysis demonstrated that a simple FORTRAN algorithm within the radar processor, based on a three-element vector model of the ionosphere, could provide the equivalent of a fast access look-up table for the entire surveillance volume of the radar.

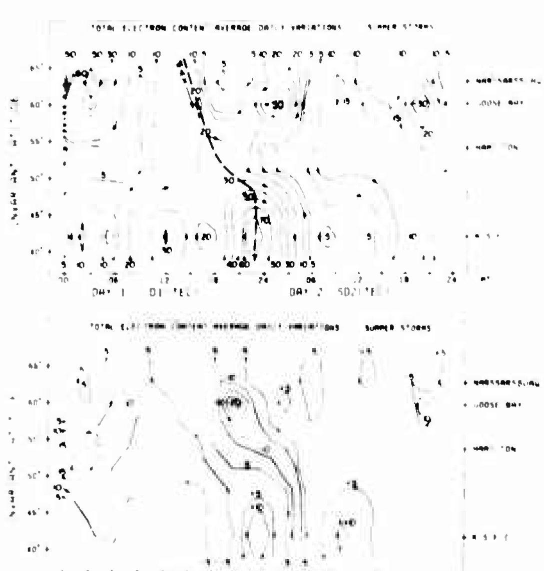
The vector model is calculated off line once a month. By removing the monthly mean ionospheric effect, it removes 75 percent of the refractive error. Since the requirements for metric accuracy on single missions still cannot be met at the peak of the day during solar maximum conditions, provision has been made for refining the correction. This is now done in two ways: first, from worldwide ionospheric observations, the Air Force Global Weather Central determines a daily update factor which



A contour plot of the difference between the monthly average total electron content and the actual value during a magnetic storm, during the winter, measured by stations in eastern North America. The heavy dashed line in the upper plot marks the time of greatest enhancement of the total electron content during the first day of the storm.

matches the monthly mean vector model to the current ionosphere; second, using a dual frequency range measurement to certain satellites, the radar determines a scale factor that provides a more precise correction. With the second technique the radar may be able to determine a scaling factor in the target area as frequently as every 15 minutes, and remove 95 percent of the ionospheric effect.

Magnetic Storm Studies: Total Electron Content (TEC) studies using Faraday polarization rotation data from VHF signals transmitted from geostationary satellites have been made from auroral to lower mid-latitude stations to study the behavior of the ionosphere during large magnetic storms. Contours of percentage variations of TEC during storms as compared to monthly average values have been prepared showing data over the invariant latitude range from 38 to 67 degrees. Large afternoon enhancements are likely due to the electro-dynamic effects associated with the dawn-dusk magnetospheric convection electric fields which produce a large upward drift of the plasma in the mid-latitudes to a region of lower loss. In the high latitudes the drifts are mostly horizontal, poleward and westward, causing ionization to pile up in the afternoon sector. Large depletions in ionization at 0400 local time at 53 degrees invariant latitude also occur due to the equatorward motion of the main trough region during magnetic storms.



A magnetic storm during the summer can cause depressions in the TEC which last much longer than those following magnetic storms during the winter.

During the later phases of magnetic storms the enhanced auroral heating produces greater molecular concentrations at F-region heights with consequent greater ionization loss rates. The resulting depressed TEC values can last several days after a major magnetic storm, especially during the local summer months, with a much shorter recovery time in the winter.

Plasmaspheric Electron Content: The launch of the ATS-6 geostationary satellite with a special ionospheric beacon transmitter allowed the first capability of making group delay measurements simultaneously with Faraday rotation measurements of the ionosphere. Faraday rotation measures electron content out to approximately 2500 kilometers height, while the group delay measures electron content out to the geostationary satellite height of 35,800 kilometers. The difference between these two quantities can be used to infer the electron content of the region above approximately 2,500 kilometers, referred to as the plasmaspheric electron content. The major new finding from plasmaspheric electron content determinations is the large difference in the average diurnal behavior observed in the United States and the European longitude sectors. In the United States longitude sector, the diurnal minimum in plasmaspheric electron content occurs near midday except during the summer months, while in the European longitudes it has its diurnal maximum near midday. The difference in diurnal shape of the two values has been explained as being due to the greatly different geographic latitudes of the magnetic conjugate regions for the two stations. The magnetic conjugate of the United States stations is in the Antarctic region while that for the European station is in the southern midlatitudes.

Ionospheric Modification Studies: In a continuing study of the effects of enhanced F_2 region loss processes, AFGL participated in Project LAGOPEDO, an effort to create a hole in the F-region by deposition of approximately 100 kg or 10^{26} molecules of water vapor into the dusk sector ionosphere near Hawaii in September 1977. A rapid decrease in TEC was seen along a path passing within approximately 1 km of the chemical deposition. A ray path from another satellite which passes approximately 80 km from the chemical deposition point showed no effects. Calculations show that the chemically enhanced loss process was perhaps only a few percent as efficient as the much larger ionospheric depletion observed due to the Skylab launch in 1973. The VHF amplitude from the geostationary satellite being observed remained enhanced by from 2 to 5 dB for at least 36 minutes after the event due to ray focusing through the hole produced by the chemical deposition.

SOLAR RADIO RESEARCH

The Solar Radio Astronomy Section of the Trans-Ionospheric Propagation Branch is engaged in making and analyzing radio observations of solar radiation in the 8 mm to 1.2 meter wavelength range, advising the Electronic Systems Division on the installation and acceptance testing of the Radio Solar Telescope Network, and performing research on the nature of various solar phenomena and their impact upon the ionosphere and magnetosphere of the earth. The observations are of two types: whole-sun observations where the antenna beamwidths are larger than the angular diameter of the sun (approximately 32 minutes of arc); and high resolution studies where the antenna beamwidths are of the order of 1 arc-sec to 4 arc-min making it possible to observe a single active region on the face of the sun. In some instances it is possible to scan the active region and develop a map. This procedure has also been used to study solar "coronal holes". The polarization of the radiation from active regions has been studied both while the region is in a quiescent state and before, during and after the occurrence of a flare.

High resolution studies of quiescent active regions at centimeter and millimeter wavelengths have shown the regions to exhibit small scale (approximately 10 seconds of arc) sources of circularly polarized (approximately 40 percent) emission. The size, intensity, and degree of polarization of these sources are very stable for intervals of time up to several days. This stability is disrupted, however, with a great enhancement of the polarization of the emission (up to 80 percent) from the region in the period up to one hour before the region produces a flare. This polarization enhancement is an indication of magnetic field changes taking place in the region. With the increase in the solar activity cycle, the search for association of this pre-burst phenomenon with proton-producing flares is being pursued.

The U-shaped radio burst has been investigated to discover if it is possible to predict the nature of the proton flux associated with it. A joint AFGL-Boston College effort has shown that the width of the interval between the frequency at which the energy peaks and the frequency at which the energy is a minimum is well correlated (approximately 78 percent) with the proton energy spectrum in the 10 to 100 MeV range. If the ratio is large, the proton spectrum is hard; i.e., there are relatively more higher-energy particles. If the ratio is small, there are relatively fewer higher-energy protons. An influx of energetic protons with relatively more higher-energy particles has a greater impact upon the earth's ionosphere, causing more severe disruption. The impact of a large number of high energy protons on satellites, manned and unmanned, is potentially devastating.

Earlier work at AFGL had shown that the particle peak flux could be related to the integrated radio flux of a burst at one frequency. This effort has been expanded to provide an improved prediction scheme

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Earlier work at AFGL had shown that the particle peak flux could be related to the integrated radio flux of a burst at one frequency. This effort has been expanded to provide an improved prediction scheme using the integrated radio flux across a broad portion of the observed frequency spectrum. The radio emissions observed in a solar burst provide an indication of what is happening at the location of the flare. The energetic protons which reach the earth do so by traveling along the magnetic field lines which extend from the sun to the earth. The solar foot point of these field lines, at approximately 57 degrees W longitude on the face of the sun, may be some longitudinal distance away from the flare location. The particles which reach the earth must travel this distance across the face of the sun, and decrease in intensity due to collisions and other processes. When adjustment for the position of the flare relative to the magnetic field lines foot-point position was made, the proton peak flux prediction method showed an 8-10 percent improvement in the correlation coefficient of the 10 MeV proton flux vs. integrated radio flux density.

One advantage of solar radio observations is that they may be carried out even when the sun is obscured by clouds. If a proton flare should occur and its position on the face of the sun could not be optically determined because of adverse seeing, the effectiveness of the radio integrated flux density proton flux prediction process would be degraded. A method has been devised at AFGL, and is now being instrumented, which uses the radio data taken by a 25-75 MHz swept-frequency interferometer to indicate the solar position of the radio burst. The interferometer also indicates the occurrence of Type II and Type IV bursts, which are associated with solar proton flares. The potential accuracy of this position determination in the east-west direction is 1.5 minutes of arc (referenced on the celestial sphere).

A small-scale study of the polarization of the peak flux density emission of radio bursts in the 5.0 to 9.4 GHz range based on August 1972-December 1973 whole-sun observations has shown that about 80 percent of the bursts in that frequency interval were circularly polarized with varying degrees of polarization. Since the study made use of only 45 bursts, the resulting conclusions about burst polarization must be treated cautiously. When the polarization increased toward the upper or lower end of the 5.0 to 9.4 GHz interval, the flux density of the burst increased in the same direction. If there was a reversal of the sense of circular polarization of the burst in the 5.0 to 9.4 GHz interval, the highest flux density of the burst usually occurred near the polarization reversal frequency.

Another source of energetic solar particles which impact the earth is the "coronal hole," a region on the sun whose density and apparent temperature are lower than its surroundings. Coronal holes usually occur in the polar regions of the sun, although some have been observed to extend from one pole to another. The first coronal hole was found by observations made from the Skylab satellite in 1973. Since that time, earth-based attempts to observe them at various wavelengths in the electromagnetic spectrum have been successful. High-resolution radio maps have been made of coronal hole regions at various wavelengths. When these radio maps were superimposed on X-ray maps, the correspondence of the radio coronal holes with those of the X-ray and EUV photographs was apparent for the larger coronal holes, especially at decimeter wavelengths. It has been experimentally determined that the largest change in radio brightness temperature for coronal holes (relative to surrounding quiet regions) occurs in the decimeter wavelength range. In September 1977, a coronal hole was detected for the first time by radio observations alone. From observations using the 1000 ft Arecibo radiotelescope, maps were produced at 21 cm and 11.5 cm wavelengths showing as much as a 30 percent decrease in brightness temperature for the coronal hole region.

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Data Processing and Display Equipment. Radar data as well as computer generated products are presented on four color displays and a CRT. Past data are available for review via the time lapse storage system.

V METEOROLOGY DIVISION

The Air Force of the 1980's, like its predecessors, will continue to feel the impact of meteorological phenomena. It is true that some operations will be less affected by weather elements. But other, and newer, operations now anticipated will involve newer and more complex systems that are weather-dependent. So the search for better methods of observing and predicting meteorological conditions has continued to be the principal effort of the Meteorology Division.

During the past 30 months, the program of the Meteorology Division has included the development and testing of automated techniques of observing, disseminating, displaying, and predicting critical airfield weather elements, methods for processing and displaying the voluminous imagery data received from meteorological satellites, techniques for the processing and display of radar data used in detecting significant features of storms and predicting their motion and severity, instrumentation and analytical methods for determining the microphysical characteristics of clouds and precipitation during reentry of hypersonic ballistic missiles, methods of modeling atmospheric circulations and increasing the efficiency and accuracy of numerical weather prediction, climatological techniques for use in the design and operation of a variety of Air Force systems, and ways of dissipating warm fog at air bases and creating holes in super-cooled stratus clouds.

Much of the meteorological instrumentation and related software has been developed for use in in-house research investigations, but other instrumental approaches have been examined to determine their feasibility for eventual use in systems to be operated by the Air Weather Service. Equipment has been developed and tested not only at Hanscom AFB but also at two field sites in Massachusetts operated by the Meteorology Division — the Weather Radar Facility at Sudbury and the Weather Test Facility at Otis AFB. Aircraft equipment has been tested on a C-130E aircraft operated by Air Force personnel, and on a leased Learjet operated by contractor personnel.

MESOSCALE OBSERVING AND FORECASTING

A fully automated system to observe, predict, disseminate, and display airfield weather could reduce the workload of weather observers and forecasters. Development of such a system has been the primary program of the Mesoscale Forecasting Branch during this reporting period. Other objectives of the mesoscale R&D program were the development of objective and automated weather prediction schemes for short range forecasting and the use of the very high resolution data available from sensors on board the Defense Meteorological Satellite Program satellites.

Automated Weather System Development: Requirements for weather support in the Air Force are variable and dependent on the mission to be satisfied. Also, significant economies can be realized by utilizing, to the fullest extent possible, weather sensors in the current inventory which can be automated. Therefore, the whole concept of the Modular Automated Weather System (MAWS) has been built around a modular design to ensure flexibility. Studies of sensor automation have addressed the full range of components of the operational, non-tactical inventory as well as the development of new instrumentation and/or specification techniques in those areas where existing sensors are either inadequate or not available. Microprocessing technology has reached levels of reliability, miniaturization and cost effectiveness which enable us to proceed with a design methodology that presumes on-site (or within-sensor package) processing of individual sensor output, suitably averaged and prepared for transmission, on request, to a central processing site.

Among inventory sensors, the AN/GMQ-20 wind set, the AN/GMQ-11 transmissometer, and the AN/GMQ-13 Rotating Beam Ceilometer (RBC) were found to be suitable for automation. The AN/TMQ-11 temperature/dewpoint set and the ML-331/TM barometer were found to be unacceptable. Automation of the transmissometer required replacement of vacuum tubes with solid state amplifiers. Our evaluation of the solid state amplifier modification kit resulted in an upgrading of its operational transmissometers. The wind set was automated by incorporating commercially available synchro-to-digital converters into a microprocessor-based interface module. The rotating beam ceilometers presented the most complex automation problems. Modifications to solid-state electronics solved most of the hardware problems. The software analyzes the sequence of five observations gathered during a one-minute duration to yield the estimated cloud base height over the observing site.

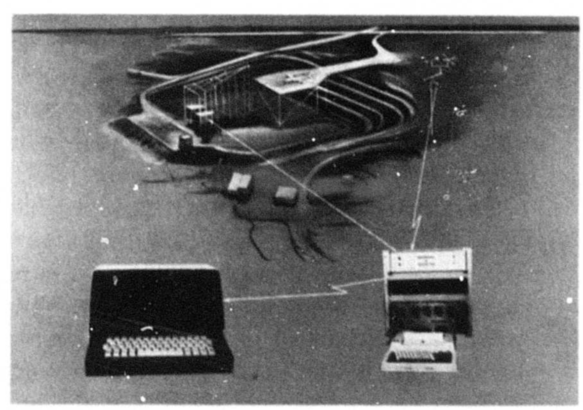
More accurate and reliable surface weather instruments are being sought to replace present instruments which have been used for a long time and to measure weather elements which now require a human observer. Several observing techniques and instruments having good potential for use in fully automated systems are being developed and evaluated at AFGL and at the Meteorology Division's Weather Test Facility at Otis AFB, Massachusetts. The Weather Test Facility was established in 1975 to permit rigorous, long-term evaluation of new and improved instruments at a location which frequently has cloudiness, reduced visibility, and many forms of precipitation.

Laser devices to sense weather elements such as visibility, cloud base height, and low-level wind profiles are being developed and tested by both AFGL and contractor personnel. A lidar (light detection and ranging) ceilometer being considered for automated ceilometry measurements uses an erbium-doped glass laser as its transmitting source. In cooperation with NOAA's Wave Propagation Laboratory, an experimental helium-neon laser device to discriminate among various types of hydrometeors and obstructions to vision has been field tested at the Weather Test Facility. Some objectives have already been satisfied. However, the Equipment Development Laboratory of the National Weather Service is now extensively redesigning the device to enable the full required capability to be achieved.

When airfield visibility conditions are close to the landing minima, the problem of measuring visibility in the approach zone becomes critical. The ability of a pilot to perceive the runway and its environs as he approaches the point on the glideslope known as "decision height" is often less than that of an observer viewing horizontally along the runway. Devices to provide the pilot with better measures of his visual range at decision height have been pursued along two lines at AFGL. An experimental lidar system employing a frequency-doubled ruby laser was contracted for in 1975. Its novel design concept offered the potential of solving the multiple scattering problem which plagued earlier designs, of having sufficient penetration capability in low visibility conditions, and of being eye-safe. The design also involved a high technical risk; to date, the instrument has not performed satisfactorily during contractor tests and at AFGL. An alternative, less technically risky solution to the problem of determining slant visual range has been tested at the Weather Test Facility and found to yield highly accurate results. It takes point measurements of visibility at the 10-, 50-, and 100-foot levels of a tower located a safe distance to the side of the runway touchdown point and translates them into an estimate of visual range in the landing zone. Studies at the Weather Test Facility have confirmed that widespread and dense fog is largely homogeneous horizontally, while it is highly variable vertically. The effectiveness of this approach has been demonstrated during several episodes of dense fog. The estimation error of this technique is only one-third the error of a commonly used ground-based technique.

A low-risk approach to present weather determination is being pursued using a decision-tree method and an array of commercially available weather sensors which had been individually subjected to rigorous evaluation during tests at AFGL and elsewhere. Ground-based and tower-mounted temperature-dewpoint sets, wind sensors, forward-scatter and backscatter meters, a transmissometer, a nephelometer, and a tipping-bucket rain gauge are used in this method. An identification rate of 90 percent has been achieved thus far in tests conducted in non-winter situations.

Wind sensors must be deployed in remote and sometimes harsh weather locations. This requirement has led to an evaluation of several commercially available sensors, some employing novel sensing principles. These include sensitive, yet rugged, cup-vane and prop-vane models; devices based



MAWS Wind System designed for the AFWL TRESTLE Program Office and installed at Kirtland AFB, New Mexico.

on a vortex shedding principle; and differential pressure probes with no moving parts, suitable for cold region deployment. Intercomparison and reliability tests are underway at the Weather Test Facility.

A prototype Modular Automated Weather System (MAWS) being evaluated at Scott AFB, Illinois, since January 1977 uses more sensors than any system anticipated to support fixed base operations in order to determine the number and spacing of airfield observing sites and frequency of observations required in an actual system. At each observing site, wind speed and direction, temperature, dewpoint and sensor equivalent visibility are measured continuously. Three surface observing sites are located adjacent to Runway 13/31 close to existing operational weather instruments located near the end points and mid-point of the runway. Observations are also gathered at the 25 and 40-meter levels of an instrumented tower offset 600 meters from the touchdown end of Runway 13.

The same type of microprocessor is used in the central supervisory station and the weather measurement sites. It has a processing unit, read-write and programmable memory units, and suitable control logic. The logic programmed into the microprocessors for the remote observing sites reads voltages from each sensor several times each minute, converts the data to appropriate meteorological units, averages the data and prepares the data for transmission to the supervisory microprocessor.

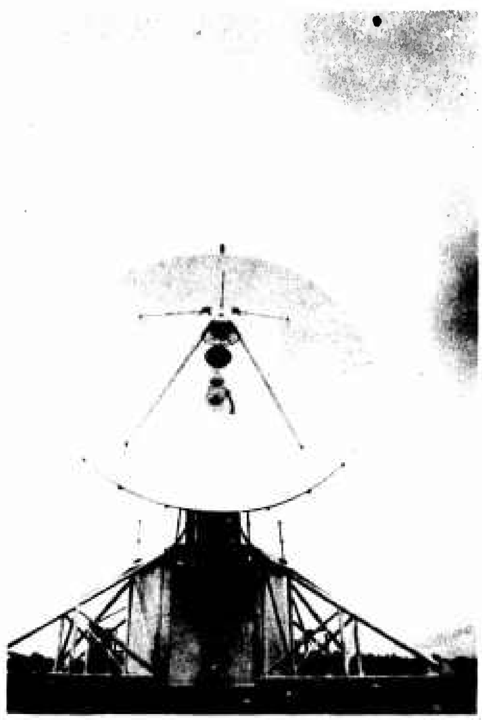
Fresh observations, updated each minute, are displayed on alpha-numeric plasma display devices in the Scott AFB weather station and AWS Headquarters. The display has four pages of output which are individually displayed each minute. These include the latest observations, comparative data from 5, 10, 15 and 30 minutes earlier, "metwatch" parameters pertinent to alerts or warnings when critical thresholds are exceeded, and automated probability forecasts of runway visual range and cloud base height for prediction intervals as long as three hours. The system has been continuously evaluated, redesigned and modified.

At the request of the TRESTLE Program Office at Air Force Weapons Laboratory, Kirtland AFB, New Mexico, a microprocessor-based wind warning system has been designed, fabricated and installed at the TRESTLE site in New Mexico by AFGL engineers and technicians. Minute-by-minute updates of wind conditions adjacent to the TRESTLE platform will be constantly available to the Test Director to ensure safe and efficient test operations. After wind data at the test site are archived for several months prior to actual operations, short-range wind prediction algorithms, adjusted for conditions at the topographically complex site, will be developed for use by Air Weather Service forecasters tasked to support test operations.

Short Range Forecasting: Rapidly changing weather events, superimposed on complex weather support requirements, in a hostile tactical environment place difficult, even overwhelming, demands on the Air Force weather forecaster. AFGL mesoscale forecasting research is aimed at developing objective procedures to aid the field forecaster responsible for forecasting critical weather elements for time periods up to six hours. Since the observations available to the forecaster in a wartime situation can range from minimal (he knows conditions only where he is located) to a full data set from all available sources, techniques are being developed which can handle variable initial conditions. Single-station, single-element statistically-based models which yield exceedance probability predictions for periods out to three hours have been developed for aviation-critical elements, such as runway visual range, cloud base height and slant visual range. Extension of these models, which rely on ground-based measurements, to include spatial and temporal variations of a particular predictand, is presently under investigation.

A potentially powerful source of tactical weather information is the meteorological satellite. Geosynchronous satellites provide frequent views of a wide area which can be used effectively in sensible weather prediction models. The meteorological satellite program at AFGL has, for the past two years, turned to developing automated data extraction, analysis, interpretation and short-range prediction techniques which rely heavily on visible and infrared geosynchronous imagery.

With a few exceptions, satellite imagery has previously been applied by subjective methods. The development of real-time methods of introducing satellite data into objective short-range forecasts is the subject of a four-pronged program. The first approach is a straight-forward statistical one. It involves using digital imagery to define and predict clouds and precipitation. In concept, the visual and infrared imagery for an appropriate sector around a selected terminal or target is extracted from the satellite's transmission stream. These data, in some cases combined with conventional data, are processed by appropriate statistical operators to generate a probability forecast. Depending on the operation which the forecast is supporting, it might be expressed as the probability that an event will occur in the next two, three or four hours or the probability of the intensity or duration of the event. The forecast is delivered to the meteorologist or the operationaw decision maker, or even entered into the computer's memory for direct utilization in a larger matrix of information bearing on an operation decision.



Antenna for Real Time GOES Data.

A second approach makes use of an interactive computer system to search for predictors by relating features and changes in the imagery with the developments in various circulation fields, including those based on winds derived from cloud displacements between geosynchronous satellite frames. A third approach is to compare computer-generated descriptions of the current "weather state" made from satellite data with weather forecasts based on numerical methods. The objective is to develop guidelines as to when and where it is best to rely either on the computer calculation of weather from satellite data or the numerically basedsforecast. The latter two approaches were recently initiated under university contracts.

Still another short-range forecasting method that can be effective is extrapolation. Techniques developed for extrapolating radar echoes, noted in the last *AFGL Report on Research*, can be used to forecast the motion of satellite-observed clouds. Two problems must be resolved for the technique to be useful. The first is that the clouds must be located accurately because the motion can be no more accurate than the initial and final positions. This navigational problem, which is critical to the other aspects of the short-range forecasting work as well, has been solved using the Man-computer Interactive Data Access System (McIDAS) to obtain the optimum adjustment of the transform between image and earth coordinates.

The second and larger problem is obtaining the motion vectors automatically. Currently we are testing four techniques for cloud displacement to see if there is any clear superiority among them. Two of the techniques involve re-arranging the cloud elements to form groups of smoothed synthetic clouds. This is called clustering. A third method uses the cross correlation between the fast Fourier transforms of the initial and final data field. The fourth method is a binary form of the cross-covariance approach. The data are reduced to a single bit per pixel which, with the use of some fast FORTRAN masking instructions, speeds up the computation of vectors. These tests are now under way.

Satellite Specification Studies: In order to use all the fine mode data generated by Defense Meteorological Satellite Program (DMSP) satellite sensors for the detection of small-scale cloud features throughout the globe, human interpretation of satellite images must be replaced by automated techniques and these techniques must necessarily be efficient. Two approaches have been developed to improve the utilization of fine mode satellite imagery. The first approach reduces the number of levels of brightness or "gray shades" needed to display the image from 64 levels (6 bits), which are currently used for DMSP visible images, down to two levels (1 bit). In a test, an original DMSP image with 64 gray shades was photographed from an AFGL McIDAS display. The bit reduction algorithm was applied and the resulting image with only two gray shades was very similar in appearance, since not only was the solid central cloud mass retained but also small or darker cloud elements. The commonly applied process is to truncate the image so that all the darker shades are made black and all the lighter shades are made white. The bit reduction algorithm picture looked much better because the algorithm replaced areas having intermediate gray shades with a very fine checkerboard of white and black cells, rather than arbitrarily making them

Top, DMSP visible imagery with standard 64 shades of gray; middle, same imagery after applying AFGL bit reduction algorithm yielding 2 gray shades; bottom, same imagery as top after applying truncation algorithm yielding 2 gray shades.

all white or all black, and the human eye interprets the checkerboard as an intermediate gray shade.

A second approach employs a spectral technique in which the original image is transformed by a two-dimensional fast Fourier transform and the resulting Fourier coefficients are used to classify the contents of the image. The Fourier transform reflects the spatial distribution of brightness in the image and estimates the sizes and organization of clouds in the image better than the first-order statistics. The strength of the classifier will be tested using imagery samples from various climates and cloud types.

Like the fine mode imagery data, new multispectral observations greatly increase the rate at which data are to be sampled, which leads to problems in data storage on the satellite, transmission to the ground, and information extraction on the ground. DMSP satellites may increase the number of imagery channels to six or more by 1982. Although these new forms of weather satellite data require fast and accurate techniques for information extraction, current operational processors for multispectral imagery data are limited. Two approaches to improved cloud identification based on multispectral analysis of satellite data have been examined under contract. The first approach used multispectral channels from infrared sounders. Cloud identification using sounder data requires extensive calculations using a spectral infrared radiative transfer model. It treats: 1) the inhomogeneity of the cloudy atmosphere by dividing the cloud layer into sublayers, 2) gaseous absorption in scattering cloud layers, and 3) the wavelength dependence of radiative transfer. The method works best when both short-wave and long-wave infrared sounder channels are used in combination because short-wave channels are more sensitive to overcast cirrus or middle level clouds.

A second study considered microwave and near-infrared channels, candidates for future DMSP satellites, along with existing infrared and visible channels as estimators of cloud features. Models of radiative transfer in cloudy atmospheres were used to estimate cloud radiance observables from satellites for varying cloud altitudes, thicknesses, mass densities, rainfall rates, and for various underlying surfaces. Separate models were generated for microwave observations only and for microwave and other spectral observations. Four different inverse models were developed and given extensive tests. These results were used to classify continuous cloud variables, such as cloud thickness. Discrete categories, such as ice or water clouds, snow surface or bare ground, etc., were discriminated by a Friedman Tree classification, which determines critical thresholds for decision-tree algorithms.

Tropical Cyclone Prediction: Forecasting of tropical cyclone movement was approached from two directions. One approach was to seek keys to storm translation in the distribution of cloudiness within a radius of several thousand miles from the storm center. The second approach was to test whether the addition of winds derived from cloud displacements to the initial wind field would improve a barotropic numerical forecast.

The technique used to search for large-scale characteristics of the cloud field as indicators of storm motion was to construct composites of satellite visible images that contained tropical storms of similar characteristics. The composite technique reinforces consistent features of the large-scale cloud distribution and mutes the random details. A second series of tests, incorporating infrared imagery in addition to the visible imagery, did not improve predictions.

Tropical storms develop and spend most of their lifetime over data-sparse ocean areas at low latitudes for which the equation used to calculate the wind fields from pressure measurements is less reliable than at high latitudes. Thus, application of numerical weather prediction techniques to hurricane and typhoon forecasting has been limited. However, when vertically averaged winds from ten levels extending from the surface to 16 km were used in a model called SANBAR, hurricane tracks were predicted reasonably well. An AFGL contractor studied cloud motion vectors deduced from geosynchronous satellite images to determine how well they approximated the vertically averaged wind. Predictions were improved when three or more cloud motion vectors can be deduced within the influence region of the storm.

MAN-COMPUTER INTERACTIVE DATA ACCESS SYSTEM

The original Man-computer Interactive Data Access System (McIDAS) was designed and developed at the Space Science and Engineering Center at the University of Wisconsin as a means of interactively processing and displaying meteorological satellite images. A duplicate system was installed at AFGL in 1975. This basic system had no real-time data acquisition capability, but was still a useful tool for weather research. During the period of this report, the system was expanded twice. In the winter of 1976-1977, a 24-foot parabolic antenna was installed at AFGL with step-track control to acquire a direct (stretched) transmission from the SMS/GOES series of geosynchronous satellites. A waveguide nsr bed receiver was assembled and, with its associated bit synchro iizerS was installed.

Following this addition to the McIDAS system, software developed by the University of Wisconsin was added to give the Meteorology Division full access to live data from the Eastern and Western geosynchronous satellites. These data were used in a number of research projects within the Division. AFGL software additions provided a capability to compute and display Environmental Severity Index values, employed by the Division in its support of the Space and Missile Systems Organizations (SAMSO) Advanced Ballistic Reentry System (ABRES) program, from a pair of visible and infrared images. With McIDAS, the Division has been able to display navigated images, obtain statistical data about a designated point, compute winds from cloud motion, enhance images in black and white or color, and read texperatures from an infrared image to provide data for support of aircraft operations, for decision-making in the ABRES program, and for improving forecasting efforts.

As the power and applicability of McIDAS became apparent, a second system modification was made by the University of Wisconsin in December 1977. This modification added a second terminal, graphics capability, and ability to acquire surface and upper air data with the system.

Following installation of the hardware, the software was modified by the Meteorology Division to work in the AFGL configuration, and the full capability for analysis and display of conventional data was on line in April 1978.

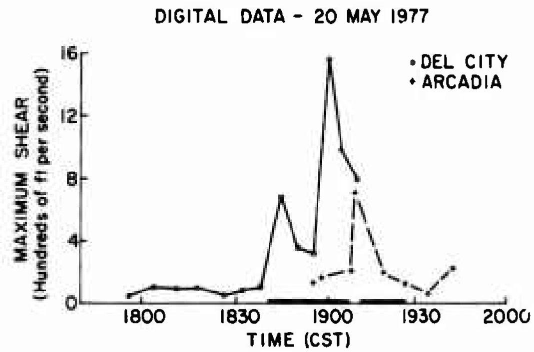
Command units for the antenna provide push-button selection of either the Eastern or Western satellite as a data source. In addition, there is the newly incorporated capability to generate and display maps of meteorological data fields, such as streamlines, isobars, heights of pressure surfaces, cloud amounts and present weather. These features have made McIDAS a more valuable facility in support of research and development in the Meteorology Division.

WEATHER RADAR TECHNIQUES

The Meteorology Division continued its investigation of atmospheric structure by radar during this reporting period, particularly in two areas where operations are based on weather radar information. One is developing improved weather radar instrumentation and data processing techniques which will enable prediction of the motion and development of significant storms reliably, and quickly enough to be useful. The other is accurately measuring and predicting precipitated water content encountered along the reentry trajectory of SAMSO test vehicles. This work is part of an overall effort to define the size distribution, phase, and concentration of hydrometeors affecting nose cone erosion of these vehicles at supersonic speeds. This work is described more completely in the Weather Erosion section of this chapter.

Both widespread and convective precipitation systems are studied at the AFGL Weather Radar Facility at Sudbury, Massachusetts. Scientists use an experimental C-band Doppler radar with state-of-the-art processing and color display equipment, an X-band weather surveillance radar, and various auxiliary meteorological sensors. Techniques, instrumentation, and software for measuring, processing, displaying, and automatically interpreting ground-based weather information are developed. During recent spring storm seasons, data on severe convective storms have also been acquired in central Oklahoma at the National Severe Storms Laboratory, in a joint agency cooperative program for the operational evaluation of Doppler weather radar technology. The Weather Erosion Program has used high-power ultra-sensitive radars at the Kwajalein Missile Range at Roi Namur, Marshall Islands, together with advanced processing and display equipment tailored to the specialized needs of these programs.

Storm Diagnosis: Doppler radar has significantly improved our ability to identify severe thunderstorms, by allowing the direct measurement of the wind structure, as well as precipitation intensity. For several years, meteorologists working with Doppler radar have qualitatively recognized the close association of severe thunderstorms with the mesocyclone, which is a vortex with a diameter of 1 to 10 km, rotating at speeds of up to 50 meters per second, located within a small region of some thunderstorms. The mesocyclone is an important feature because it is a very reliable precursor, while it is still aloft, of tornadoes or other types of destructive weather occurring minutes later at the ground. This behavior pattern of mesocyclones provides the basis for much better severe storm warnings, but quantitative prediction of the time, place, and intensity of storm damage at the ground is not yet possible.



The development of maximum shear across the mesocyclones which produced the Del City (solid line) and Arcadia (dashed line) tornadoes. The duration of the two tornadoes at the ground is indicated by the heavy solid lines along the base of the diagram. Large values of shear are very closely associated with the appearance of tornadoes at the ground.

During the operational evaluation of Doppler technology in Oklahoma, several mesocyclones and their accompanying tornadoes were observed and recorded. The development of these mesocyclones was studied to enable prediction of the time when the tornadoes would touch the ground. The maximum shear, or change of wind velocity across the mesocyclone, was very well correlated with tornado occurrence. The height of maximum wind speed and of minimum diameter in the mesocyclone descended by 3 to 5 km prior to a tornado. Another parameter strongly associated with tornado touchdown is the minimum height of zero divergence. This is the height at which all wind motion contributes to rotation, with virtually no air entering or leaving the vortex. This pilot study will be expanded to many other cases in search of a reliable way to predict the time of surface damage.

Heavy snow disrupts activity by temporarily closing runways (and roads) and by reducing visibility. The accuracy limits on estimation of snowfall rates by measurement of radar reflectivity were studied. The great variability in snow crystal type, snowflake size, and especially wetness of the snow when it falls through temperatures slightly above 0 degrees C make snowfall rate considerably more difficult to estimate than rainfall rate.

Skilled observers made a total of 187 measurements of snowfall in six coastal snowstorms during January through March of 1978. Corresponding values of radar reflectivity were averaged during each of the measurement periods, for each location. The data for each storm covered a wide range of snowfall rates and radar reflectivities. A correlation of radar reflectivity and snowfall rate indicated that radar is useful for remote estimation of snowfall rate, provided that surface reports assure that the snow is dry.

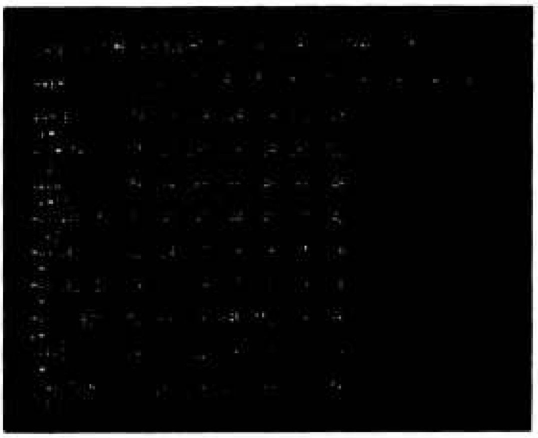
When hurricane Belle invaded southern New England in August 1976, the weather radar was used to study some of its features. Landfall had caused disorganization of the eye of the storm before it came within range of the radar, but several of the hurricane rain bands passed over the radar site and were observed with suitable resolution. Curvature of the wind field in the innermost rain band was evident, consistent with a model with a small radial flow toward the hurricane center combined with a mainly tangential flow around the center. The measurements also showed wind speeds decreasing with increasing distance over land, and the existence of a small-scale wave pattern superimposed on the large-scale wind field. These observations are not only intriguing, they are also the first reported measurements by Doppler radar of the wind structure in a hurricane.

Weather Radar Instrumentation: In recent years, large-scale radar data processing systems have been developed to generate weather information in real time. While these systems offer considerable promise, automatic system calibration and ground clutter suppression devices are needed to make them more effective. Laboratory and contractor scientists have recently developed instrumentation to overcome these limitations.

Both Doppler and conventional radars can be calibrated with a newly developed test set which provides continuous pulse to pulse calibrations of the transmitting and receiving equipment. The peak power in the transmitted pulse is measured by comparing it to a known power level. The measured power level of the pulse is represented by the coding of a pulse train of constant amplitude. The amplitude of this pulse train is used to calibrate the entire receiving system, and the decoded value of the transmitter pulse power provides the information needed so that the transmitter can be calibrated. This approach may provide an automated means of standardizing the network of radars operated by the Air Weather Service and the National Weather Service.

Interference from ground target returns is a problem for Doppler as well as conventional radars. Doppler weather radar spectral moment processors, such as AFGL's Pulse Pair Processor, are particularly sensitive to ground clutter because these processors use the entire unambiguous velocity range of the radar, which includes both weather phenomena and ground clutter. A filter has been developed which cancels ground echoes at all ranges. Tests of the filter indicate that it rejects 99.99 percent of the signals from objects moving less than 0.32 meter per second, while signals from weather targets with velocities greater than 1 meter per second are passed undiminished. Ripple introduced by filtering is less than 1 dB over the unattenuated portion of the velocity band. This clutter filter greatly improves the accuracy of Doppler spectrum mean and width estimates.

Weather Radar Data Automation: Although the trained radar meteorologists in the Laboratory have used Doppler color displays to demonstrate the superior capabilities of Doppler radar, operational Air Weather Service stations do not have such highly trained observers to interpret complete weather radar data. To give the benefits of this new technology to operating



ETSE Attribute Listing. Significant attributes of the detected cells are summarized for easy assimilation by the forecaster. The cells are labeled for cross reference with the color display tracks.

organizations without requiring increased training of potential users, a data processing system has been designed. This system, called the Echo Track and Significance Estimator, or ETSE, provides a summary list of radar-derived attributes of each storm cell as well as the cell's past storm track and forecast track. Newer developments in Doppler weather radar meteorology can be incorporated into the analysis and forecasting by changing the programming.

Algorithms are developed and encoded on the ETSE to test realtime methods of data analysis. A precipitation area is considered significant if its radar reflectivity and size each exceed certain predetermined values. Attributes computed for each precipitation area include area centroid location, reflectivity-weighted area, maximum velocity, maximum spectral width, and speed and direction of cell movement. The computer also uses consecutive radar scans to generate a color display of present outline, past track, extrapolated position and the attribute listing number of each echo area together with a listing of observation and forecast times. A map of the local area is an overlay for the meteorological information.

Operational Test of Doppler Technology: The National Weather Service, Air Weather Service, National Severe Storms Laboratory, Air Force Geophysics Laboratory, and the Federal Aviation Administration have joined in a program known as the Joint Doppler Operational Project, to evaluate Doppler weather radar for operational applications and to develop specifications for an advanced system which all these agencies can use. The system will replace the aging FPS-77 and WSR-57 systems in the national weather radar network. However, the final system should not only make the routine observations made in the present national network but also be able to measure the internal structure of severe thunderstorms to provide warnings of tornado-like winds, large hail, and dangerous turbulence.

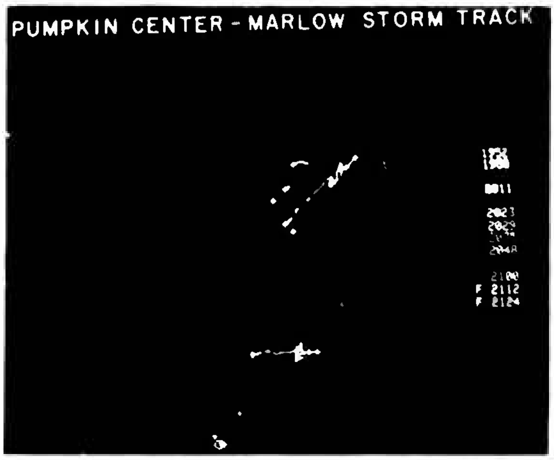
During the spring months of 1977 and 1978, Doppler radar technology was tested in operation, using the experimental Doppler radar of NSSL, supplemented by data processing and display equipment of AFGL and NWS. Tornadoes and other severe convective storms were identified by the mesocyclones they contained. A mesocyclone has the unique velocity signature on the display of a velocity maximum adjacent to a velocity minimum at the same range, persisting for at least several minutes and extending several km in height. High velocities at ground level indicated damaging windstorms. When they recognized severe weather, project personnel transmitted advisories to affected civilian and military weather forecast offices located throughout

Oklahoma and in adjacent areas of Texas, Kansas, and Arkansas.

The warnings issued by the Joint Doppler Operational Project were compared with warnings issued by the Oklahoma City Weather Service Forecasting Office, which did not have the benefit of Doppler information. Doppler technology achieved a probability of detection slightly greater than conventional methods, but had less than half its false alarm rate. Another significant advantage of Doppler was its lead time, which averaged 21 minutes, and greatly exceeded this value for the most destructive and largest tornadoes. Conventional methods, on the other hand, rely on human spotters, who do not detect a tornado until it descends below the cloud base. Conventional techniques, therefore, required almost two minutes after the tornado touched down before a warning was issued.

During the second year of testing, one large tornado was identified as a life-threatening storm nearly 40 minutes before it touched down. The advisories allowed all residents of the threatened area plenty of time to get into their storm cellars or drive away to a safer location. The Echo Track and Significance Estimator was also put into operation during the second year. During an outbreak of severe storms on April 5, 1978, this automated system showed a significant shift in the direction of motion of a storm which had developed an intense mesocyclone, indicative of a tornado. This change was put into the advisory, resulting in a changed warning which alerted residents who had previously thought the danger would pass well to their north. The tornado struck along the revised track, but the residents had taken action to escape the tornado.

The tests also demonstrated a capability for recognizing low altitude wind shear which could be dangerous to aircraft landing or taking off. On one occasion, a shallow gust front was generated by very ordinary thunderstorms embedded within widespread precipitation. Descent through this gust front, which was completely obscured by clouds and precipitation, would have been extremely dangerous for an airplane trying to land. Below an altitude of 1 km, the head winds would have shifted to tail winds at an accelerating rate. The loss in airspeed would have been 50 knots by the time the aircraft reached the head of the gust front at an altitude of 200 to 300 meters. Remote sensing of such dangerous wind shear by Doppler radar can provide the warning needed to aircraft.



Display of storm tracks for April 5, 1978, superimposed on county map of Oklahoma. Shaded area surrounding "1" marks position at 2054 CST of storm which produced the Marlow tornado. Past positions, extending westward, are coded in color on the original display and matched to color-coded times listed along the right.

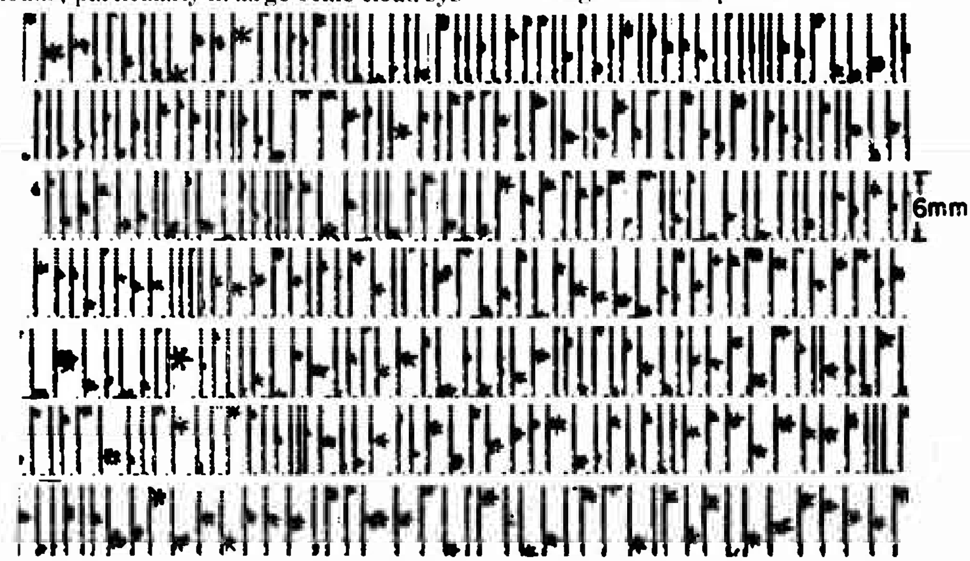
CLOUD PHYSICS

The cloud physics program is directed into five areas. One of these areas, measurement and forecasting of cloud, rain and snow types and particle size distributions for weather erosion testing of reentry vehicles, absorbed almost all of the resources of the cloud physics effort from 1972 through 1977. The other four area of cloud physics are: development of airborne cloud physics instrumentation; determination of characteristics of high altitude cirrus cloud particles; investigations of cloud, rain and snow types, associated particle size distributions and ice/water contents in large-scale cloud systems as storms develop and cross the United States; and development of statistics of water content, cloud, rain and snow types with their particle size distributions for Air Force applications. Two AFGL-instrumented cloud physics aircraft, an MC-130E and a Learjet 36, were used to obtain data for real-time mission control decisions, for post flight analysis, and for research studies.

The contributions of the cloud physics program to weather erosion testing are presented in the next part of this chapter.

Information on the microphysics of clouds, particularly in large-scale cloud systems, is inadequate. Data on particle types, size distribution, and ice versus liquid water content are rare and localized, and most have been taken in unusual storms. A systematic study of the microphysics of large-scale cloud systems was begun in October 1977 to acquire an adequate data base of cloud physics information for Air Force development, test, and operational needs.

An analysis of Air Force needs has shown a need for instruments to measure the mass of high-altitude cirrus cloud particles and for instruments to measure ice/water content in the melting layer where large snowflakes melt into raindrops while falling through the atmosphere.



One of the better examples of stellar crystals recorded by the laser shadowgraph. Pattern recognition techniques developed at AFGL have been incorporated in a microcomputer system for real-time, automatic classification of hydrometeors. The vertical bar on the left of each detected particle contains time and other information which are used in the computation of the number of particles per cubic meter and the ice/water content of the clouds.

Microphysics of Clouds: The Air Force needs improved techniques of observing and predicting physical characteristics of cloud and precipitation particles for the operation of aerospace vehicles, weapon systems and communication systems. Statistical data on cloud and precipitation size distributions and types of rain, snow or ice crystals are needed for weather erosion effects, electromagnetic weapon systems, satellite communication systems and advanced numerical weather prediction models. In addition to the direct support to SAMSO, AFWL and AFFTC, AFGL began a basic research program to expand the inadequate data base for present and future applications to Air Force problems and needs. On two separate occasions, the instrumented MC-130E sampled winter storms on successive days as the storms formed, developed and changed while moving from New Mexico to the East Coast.

Hydrometeor particle types, size distribution, ice/water content values and standard meteorological data were collected by the MC-130E, while satellite data were obtained by McIDAS. These data have been analyzed for inclusion in statistical summaries. Data taken by the aircraft and by McIDAS for other programs are being reprocessed to provide additional data for the summaries.

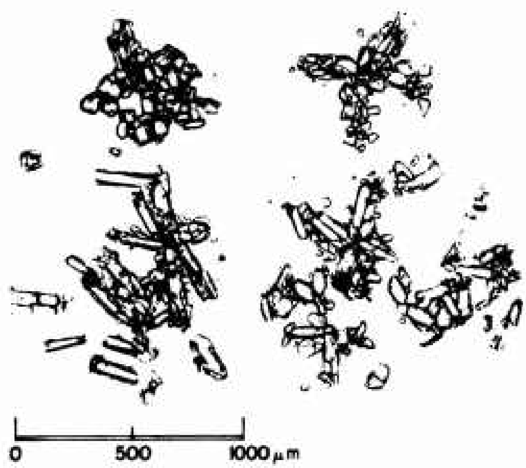
Observations show wider variations in crystal types than those reported earlier in the literature or obtained from cloud chamber experiments. A definite geographic variation has been observed in single crystal types, with more pristine crystals observed in the Midwest and a larger percentage of malformed or undefined crystals found over the East Coast.

Ten flights were made into cirrus clouds with the Learjet during August and September 1978 to provide summertime data above the flight ceiling of the MC-130E. The missions were flow in Oklahoma and New England. Cirrus clouds from thunderstorms as well as those generated *in situ* were sampled, their characteristics being added to the data base.

Cloud particle data collected by the MC-130E in halo-producing cirrus did not exhibit the large abundance of pristine crystal shapes thought to be required for optical phenomena. We speculate that the fact that a halo was observed in spite of the non-pristine nature of the crystals was due to the relatively small variation in particle size and the relatively low concentration of particles.

Instrumentation Development, Test and Evaluation: There are two regions in the atmosphere where it is particularly difficult to measure the liquid water content of the atmosphere — at high altitude where the cirrus particle shapes cannot be resolved by two-dimensional shadowgraphs and axial spectrometers, and in the large snow and melting zone region where the particles are irregular in shape and density and are larger than the sampling area of the spectrometers. In this latter region, where liquid water contents can be quite high, two instruments, called EWER and TWCI, each using a different approach, have been under development, test and evaluation.

The EWER, an instrument originally designed to Evaporate the Water that aggravates Erosion on Reentry, has two sampling tubes, each with a sampling area of 10 square centimeters. One tube samples air only, and the water vapor content is determined by measuring the attenuation of a Lyman Alpha source due to the ambient water vapor. The other tube collects the ice or liquid water which is rapidly converted to water vapor and then measured in the same way. The difference between these two water vapor determinations is the amount of water contributed by the ice or liquid water collected. From the sampling area and the aircraft speed, the volume sample per second is computed and the amount of liquid (or solid) water in grams per cubic meter is determined. This instrument has been calibrated against the shadowgraph spectrometers in rain where raindrops are spherical and the spectrometers have their greatest accuracy. Time variations of the



Examples of agglomerated columnar crystals collected in cirrus clouds when a 22 degree halo, parhelia (mock suns), a sun pillar and an undersun were observed. These cirrus cloud particles did not exhibit the pristine crystal shapes normally thought to be associated with the observed optical phenomena.

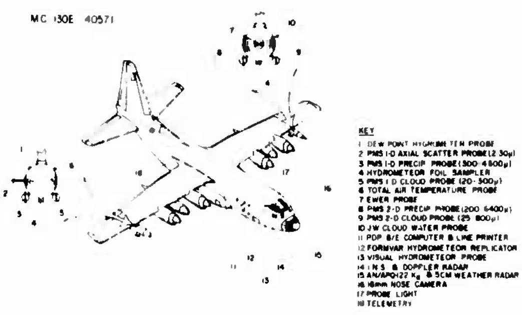
EWER and spectrometers are highly correlated, but baseline variations indicate that the Lyman Alpha detector operates over a broad band near the Lyman Alpha line and, hence, does not operate according to theory.

TWCI is an acronym for Total Water Content Instrument and operates by mixing liquid water with a carrier fluid and measuring the change in the dielectric constant of the carrier fluid caused by the addition of water to the fluid. The TWCI has a sampling area of 20 square centimeters, so it too will provide statistically reasonable sampling volumes for large particles. Initially designed for installation in the nose of the Learjet, the TWCI received limited flight testing in the aircraft. It is now being redesigned for installation in the MC-130E so that it can be flown through the same storms as the EWER to provide valid evaluations of the two instruments and the two techniques.

The difficulty in measuring ice water content in cirrus clouds stems from the fact that cirrus clouds consist of small ice crystals whose size and shape, or type, cannot be resolved by present instrumentation.

In-house scientists began the evaluation of new techniques to determine their potential for quantitative measurement of ice water content of cirrus clouds. One approach measures the electrical output of a piezo-electric crystal when impacted by a cirrus particle, with the output being proportional to the mass of the particle. This gives a direct measurement of the liquid water content of an ice crystal, but considerable development will be required to determine sensor sizes for various ice crystal size ranges and to determine the efficiency of collection for each probe. This and other possible approaches will be incorporated into our instrument development program in the near future.

The cloud particle replicator can collect replicas of particles from 2 microns to 1,000 microns. This is a continuous replication instrument which uses a formvar solution on movie-type film. As the solution dries, a



The AFGL MC-130E cloud physics aircraft is specifically instrumented to measure clouds, rain, snow and ice crystals up to a height of 30,000 ft. The data are processed by the on-board computer for use by the mission director or sent to the ground-based weather team directly from the computer over a teletype downlink.

"cast" of the particle is left on the film. Several laboratory tests were run to assure the proper flow of formvar solution to the film. The unit has been flown on several missions and has operated quite well. A television camera and monitor have provided real-time viewing of the moving film. By observing particles on the monitor, crew members can make flow adjustments during a mission, thus assuring the collection of usable data.

A foil sampler is used to obtain size information on the large snow particles. The data from this instrument are very important in the interpretation of weather radar data. New printed circuit boards were designed and installed to reduce maintenance, mechanical and electrical problems, and to improve the reliability of the foil instrument.

Improvements have been made in the One-Dimensional (1-D) Optical Array Spectrometer System and the Two-Dimensional (2-D) Optical Spectrometer System on both the MC-130E and the Learjet. The 1-D system utilizes three laser probes, which illuminate the particles passing through the object plane of an imaging system and shadow a diode array. The particles are sized from 2 to 4,500 micrometers in 45 channels and recorded on a digital recording system. Real-time computations of liquid water content are provided by the on-board computers.

The success of these instruments led to the development of the 2-D system, which produces a digital shadowgraph of each particle. The size range was also extended to 6,400 micrometers, with the lower cutoff at 25 micrometers. This 2-D system vastly improved our method of defining the shape and orientation of particles. A remote 2-D display was added to the aircraft system to aid the on-board meteorologist in classifying particle types in real time. Pattern recognition techniques were developed for processing the 2-D data to automatically determine classes of snow or ice crystals. These techniques were then incorporated in a microcomputer system in the Learjet to provide this information in real time.

The on-board computers have been updated and downlinks have been installed to transfer data from the computers to teletypes located with the ground-based weather team at Kwajalein. Computer programs were developed to provide specified data for the various types of missions.

Support of the Air Force Weapons Laboratory: At the request of the Air Force Weapons Laboratory, the Cloud Physics Branch measured atmospheric water and ice particles, so that the Weapons Laboratory could quantitatively determine their degrading effects on laser energy transmission. The MC-130E aircraft measured the size and number of particles in two regimes of the atmosphere. The thin cirrus clouds found at altitudes above 18,000 feet and the moist layer of air below 1,000 feet over the ocean were both of interest to the AFWL Advanced Radiation Technology Program.

Eight flights in the late winter and early spring of 1978 have provided data on typical cirrus clouds. All of the flights were over the U.S. Southwest. AFGL personnel aboard the aircraft directed the flights and operated the computer and other instrumentation. Cirrus ice crystals as large as 2 millimeters have been detected; however, there was usually not more than one such crystal per cubic meter. As crystal size decreased to 0.1 mm or less, the concentration typically increased to 1,000 to 10,000 per cubic meter. The visibility reduction correlated well with the quantity of larger ice crystals in a cloud. However, on a number of occasions, ice crystals as large as one-half millimeter were recorded when the visibility was 80 to 100 miles.

A sampling flight 30 miles west of San Francisco investigated water droplet concentrations above the ocean. Several passes were made at altitudes between 100 and 1,000 feet. Although there were no clouds and only slight haze, the concentration of very small particles was much less at 300 feet than at 100, 200, and 400 feet altitude. The concentrations at 500 feet and higher were also much smaller. The larger concentrations of particles in the lowest 500 feet above the ocean appeared to be at about the levels where very thin, darker haze layers were observed visually.

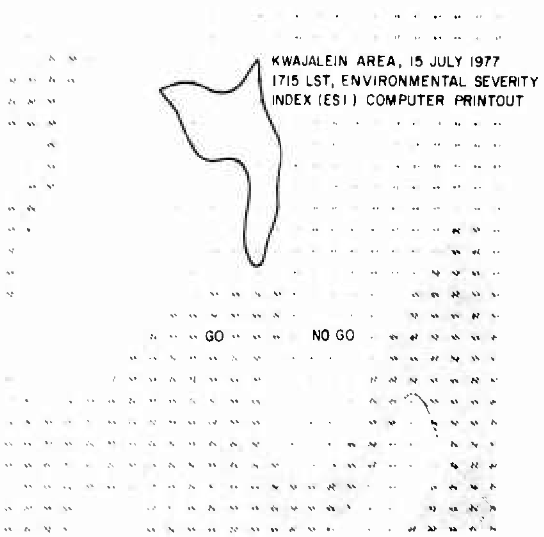
Special programs written to run on the AFGL computer were used in processing the large amount of taped digital data acquired on the sampling aircraft. Information from the flights was provided in several formats compatible with AFGL and AFWL requirements.

High resolution satellite pictures acquired every half hour from AFGL's McIDAS facility facilitated determination of when to make particle sampling flights and where to direct the aircraft.

Support of the Air Force Flight Test Center: The Air Force Flight Test Center (AFFTC) is responsible for performing in-flight icing and water tests on Air Force aircraft. To produce water drops similar to those found in natural situations, a KC-135 tanker has been modified with a spray nozzle on the end of the refueling boom. AFFTC asked AFGL to measure the drops in flight using equipment on the MC-130E to verify that the desired sizes were produced. A test flight in April 1975 showed that the correct size drops were not produced. The nozzle was redesigned, and in June 1978 a second set of calibration flights was conducted in preparation for AFFTC icing tests on the F-16. Although an airborne emergency curtailed the test, nine data points were obtained. Initial results look good, and the tests are scheduled to resume in January 1979.

WEATHER EROSION PROGRAM

After weeks and months of waiting for the prescribed type of weather, reentry erosion tests were successfully conducted in December 1976 and March 1977 at NASA's Wallops Island Range, Virginia, bringing to a close six consecutive winter seasons of testing there by the Advanced Ballistic Reentry Systems (ABRES) of the Air



Computer printout generated in real time by McIDAS, depicting erosion potential of clouds in the vicinity of Kwajalein on a day when ANT-2 was stood down because of unsuitable weather. Distortion of the atoll is due to the extreme viewing angle of the geosynchronous satellite which is stationed some 60 degrees east of Kwajalein.

Force Space and Missile Systems Organization (SAMSO). Throughout the years of testing, it was AFGL's responsibility to provide specialized weather input to the launch decision and, after the shot, to characterize the hydrometeors actually encountered along the test trajectory.

Meanwhile, at the Kwajalein Missile Range in the southwest Pacific, erosion testing of quite a different character was emerging in the form of the "severe-clear" test. While the requirement for normal weather testing is to insure that the test vehicle will encounter a specified total amount of water and ice along its trajectory, the requirement for a severe-clear test is that there be no hydrometeors greater than a certain size, usually in the 50-150 micrometer range. The entire burden of verifying this condition falls on the aircraft sensors, since low concentrations of hydrometeors are undetectable by even the ultrasensitive radars used by AFGL. Because of the emphasis on high altitudes, it is the Model 36 Learjet, rather than the MC-130E, which is AFGL's workhorse in supporting severe-clear missions.

For heavy-weather tests, one of the main gaps in the aircraft instrumentation continues to be a device for directly sensing the water content of clouds and precipitation, which is the weather factor of greatest importance in the erosion of materials at hypersonic speed. Two different devices have been built and tested, but without spectacular success. One, however, shows sufficient promise that a new model is being designed.

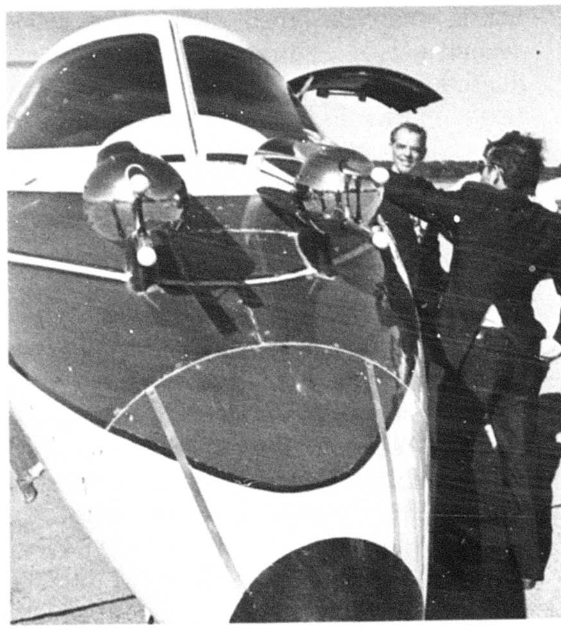
Because no instrument would sense water content directly, AFGL originally intended to derive water content from readings of the airborne particle spectrometers, which count and size the hydrometeors in a defined volume of the airstream. Unhappily, it was quickly discovered that the value of water content so inferred is frequently wrong because it depends on particle geometry, which is complex and poorly known for ice hydrometeors. Circumvention of this intolerable situation has come from an advance in theory, specifically the invention of a novel spectral function which is far less sensitive to uncertainties in particle geometry, and which can be combined with radar reflectivity to yield a value of water content that is far more reliable than that obtained from integrating the particle size spectrum.

Increasingly, real-time data from the two cloud physics aircraft, as well as radar data, have been used at Kwajalein in deciding when to launch the mission for optimum effect. Digital downlinks have now been designed for and installed aboard both the Learjet and the MC-130E. Every minute, or more often if required, each aircraft automatically transmits an updated report to a teleprinter on the ground. Onboard computers give the AFGL Field Director a wide range of options for content of the aircraft reports — from direct readout of individual sensors to complex derived quantities such as several spectral integrals.

Besides supporting erosion tests, AFGL has continued to provide SAMSO and other agencies with erosion climatologies for target and test areas. The satellite-correlation technique, which was expressly developed for this purpose and which requires as input nothing more than standard meteorological satellite data, was exploited to generate a year-long series of daily maps of four erosion indices covering the entire Eurasian area. Another of AFGL's techniques was used to construct three hourly profiles of water content at Kwajalein for the entire year of 1975. This series was designed as a statistical base for test planning.

While the satellite-correlation technique was originally conceived for climatological application using orbiting satellites, it has been adapted most profitably to real-time applications with geostationary metsats and AFGL'S McIDAS. Subsequently, whenever the Weather Team was at Kwajalein, they obtained via telephone from Hanscom current observations of weather approaching Kwajalein, in terms not available from any other source: erosion potential of clouds, their temperature, and motion.

After each erosion test, AFGL documented the trajectory weather on two occasions: in a quick-look report at 48 hours



This Learjet 36 was instrumented under the direction of AFGL to obtain cloud physics data up to a height of 45,000 ft. in support of SAMSO weather erosion projects conducted at the Kwajalein Missile Range in the Marshall Islands. Instruments on the nose and wingtips provide laser shadowgraphs of cloud and precipitation particles. These data are processed by the on-board computer to provide real-time liquid water content values and other parameters which are required for the decision to launch the SAMSO ICBM vehicle from Vandenberg AFB, California.

and in a final report at 60 days. The quick-look depended essentially on radar data, nominal relations being used to derive water content. The final report was based on tailored relations derived from detailed analysis of the joint aircraft and radar data. For ANT-2, launched on July 4, 1978, the final values of water content were substantially larger than the quick-look values. Similar experience, but less extreme, had occurred on earlier tests in heavy weather. This suggests that the nominal relationships, based mainly on data taken in temperate latitudes, are probably not representative of average conditions on Kwajalein. Consequently, AFGL is now re-evaluating these relationships for Kwajalein, using exclusively its own data taken at Kwajalein.

After eight years of evolution, the aircraft-radar methodology that AFGL has used to support erosion tests — both the launch decision and the post-flight analysis — has reached the stage that its routine application no longer requires research scientists. In recognition of this, at AFGL's initiative, this kind of test support is being converted to an inherent range capability. Thereafter, AFGL will concentrate its efforts on the developmental aspects of weather erosion problems, such as the use of lidar instead of radar for improved performance in light weather.

ATMOSPHERIC MODELING

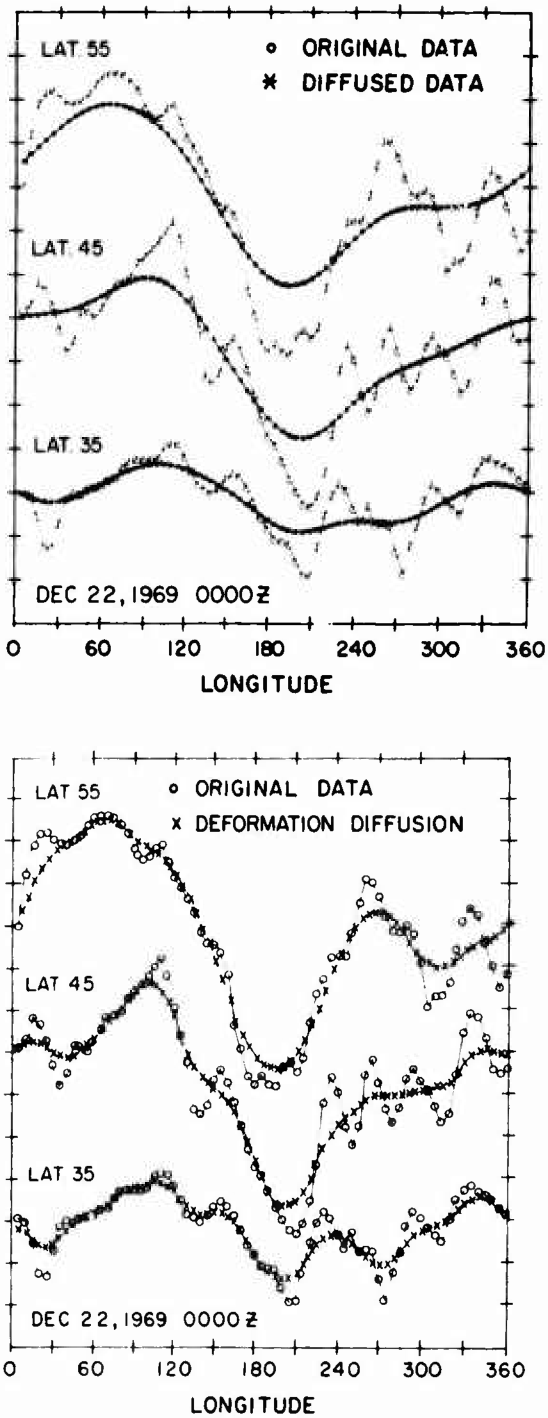
The atmosphere is a complex fluid system that responds to external forcing and internal dynamics on a continuum of space scales from the molecular to the global and with time variations, appropriate to the space scale, from seconds to millenia. Although the atmosphere obeys the classical laws of fluid dynamics, the nonlinear partial differential equations governing its behavior cannot be solved analytically. Prior to the development of the computer, theoretical studies of the atmosphere were based on linear analogues of these equations. These analogues were mathematical models of the atmosphere, but because they were based on small amplitude approximations, they were not suitable for weather prediction.

Computers have allowed the emergence of a new field of atmospheric research called numerical weather prediction (NWP). NWP is the prediction of atmospheric behavior based upon numerical solutions of the nonlinear partial differential equations expressed as an initial-boundary value problem. However, in spite of the power of modern computers, it is not possible to solve these equations in a manner which even approaches their complete general form, so here, too, the atmosphere must be approximated or modeled.

There are three fundamental sources of error in these models which require sustained efforts for reduction. Because NWP is the solution of an initial-boundary value problem, the accuracy of the prediction is directly related to the completeness and accuracy with which we can specify the state of the atmosphere at the beginning of the forecast period. Accuracy of prediction also depends upon the validity and completeness of the physics which is represented by the system of equations comprising the mathematical model. Finally, the numerical solution requires discrete approximations of the continuous differential equations in the model. Consequently, the accuracy of prediction also depends on how well the numerical method of solution approximates the theoretical analytical solution. The goal of AFGL's efforts in mathematical modeling of the atmosphere is to minimize all three sources of prediction error.

Efficient, Accurate Model Solutions: Simulations or predictions of atmospheric motions by numerical models invariably encounter the following dilemma. If the model is formulated only for a limited geographic region of the globe, artificial and often inconsistent boundary conditions must be supplied *a priori* on the lateral boundaries; if, on the other hand, the modeling is for the entire global atmosphere, the geometric complexity of the problem often gives rise to mathematical and numerical difficulties.

A case in point is the numerical solution of the classic vorticity equation model of atmospheric planetary waves. A solution in spherical coordinates for this relatively simple model is not easily obtained. The coordinate singularity at the poles, the convergence of meridians with latitudes, and the nonlinear latitudinal variation of the Coriolis force all contribute to the difficulty of the model solution. Thus, in theoretical studies, the variation of the Coriolis force with latitude is assumed to be linear to alleviate the mathematical complexity of the



Comparison of the effect of various diffusion operators and scale-dependent filter on sea-level pressure data around latitude circles after 10,000 iterations. A. Linear (Fickian) diffusion. B. Non-linear diffusion. C. More complex nonlinear diffusion. D. Scale-dependent filter. Note meteorological features which are smoothed out by the diffusion operators.

problem. In NWP applications, a model similar to this one has been traditionally applied, using a polar sterographic projection.

We have developed an efficient, accurate finite-difference method for the numerical solution of such models in a global setting. This novel method incorporates an efficient direct solution technique for a Poisson equation on a sphere and it uses a flexible-increment concept in finite-difference approximations to overcome the problem of computational instability due to the convergence of meridians in polar regions. Test calculations have demonstrated that the behavior of simple planetary waves can be predicted accurately for up to 100 model days in roughly 260 seconds using a CDC 6600 computer. Thus, both in terms of computational stability and efficiency, this method of solution for the vorticity equation model seems to provide a valuable tool for numerical experimentation.

Filtering and Smoothing: Numerical integrations of finite-difference analogues of systems of nonlinear partial differential equations, such as those arising in NWP, are subject to computational instability from a variety of causes. One type of instability is produced by a spurious, nonlinear growth of high-frequency components that may be introduced by roundoff, truncation, and observational error. This type of instability, arising from numerical noise, can be suppressed by a suitable choice of finite-difference method or by the use of a filter that selectively damps the high-frequency components. Though much effort has been devoted to the development of stable finite-difference procedures, and considerable success has been achieved, all such methods involve high-frequency smoothing, either implicitly or explicitly.

In addition to the noise inherent in the numerical integration procedure (numerical noise), there is real noise which arises in a nonlinear system from a cascade of energy from large-scale motions to smaller and smaller scales. In the atmosphere, this real noise is controlled by diffusion and viscous dissipation, which is the final stage in the transfer of kinetic energy from larger to smaller scales. Numerical models of the atmosphere must handle not only the numerical noise from the integration procedure, but also the real noise arising from the nonlinear processes being modeled. To complicate the problem further, the smallest scale which the model can resolve (twice the basic grid spacing) is many orders of magnitude larger than the microscopic scale on which viscous dissipation occurs in the atmosphere. Therefore, the model cannot treat viscous dissipation as the atmosphere does, but must introduce some arbitrary, artificial procedure which acts on much larger scales of motion. The crux of the problem is that the artificial dissipation must be strong enough to damp the noise which is constantly being generated, but must be weak enough so as not to damp the larger-scale, meteorologically significant variations. This means that the artificial dissipation must have the characteristics of a highly scale-dependent filter with strong damping for small-scale variations and little or no damping for only slightly larger scales. We have developed a filter which is ideal for this purpose. The filter completely removes variations on the smallest resolvable scale of the model, the two-grid-interval wave, but it can be made as highly scale-dependent as desired. The operator is symmetrical and does not alter the phase of any wave component. Furthermore, it is simple and efficient to use as part of the numerical integration procedure.

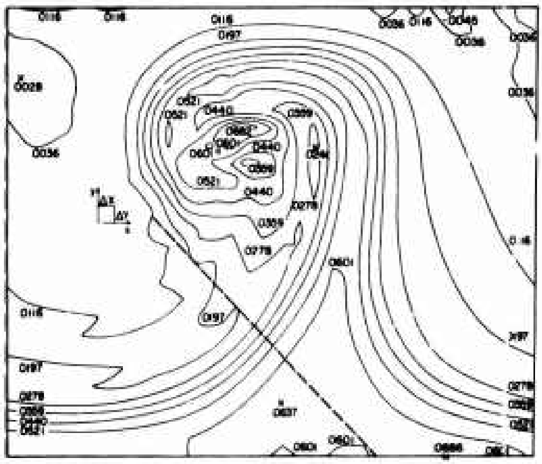
Because of its highly desirable characteristics, the filter has been adopted by a variety of agencies, both in this country and abroad, for use in both operational and experimental weather prediction models.

Numerical Modelling of Fronts: In the past few years, improvements in the speed and capacity of computers have made it possible to model and study small-scale atmospheric features, such as frontal systems. Although fronts may extend for thousands of kilometers in length, they represent transition regions with large differences of wind and temperature over relatively small distances across the front. In modeling fronts, the problem of noise suppression is extremely acute since the dimension of the physical system is not much larger than the two-grid interval noise scale of the model. The scale-dependent filter discussed above has recently been applied to the modeling of fronts. The use of a relatively low-order filter has made it possible to carry out extensive integrations of a model designed to study the development of fronts, without the contamination of small-scale noise.

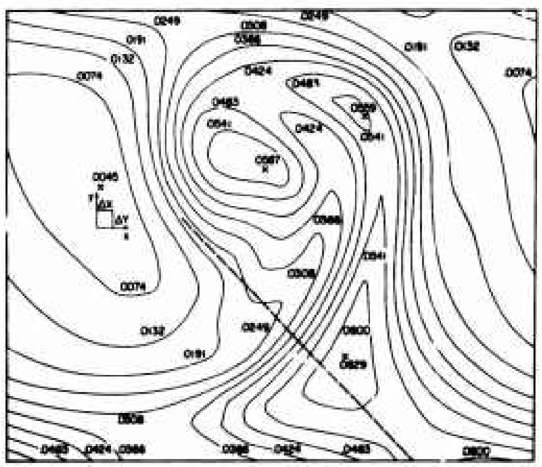
Limited Area Solutions: Routine prediction of atmospheric behavior, particularly the prediction of the gross features of the large scale circulation, is commonly based upon the numerical solution of a mathematical model designed to incorporate the physics for those atmospheric features of immediate interest. The typical mathematical model consists of a set of nonlinear partial differential equations expressing the rate of change of momentum and heat (the prognostic equations) and an appropriate set of diagnostic equations expressing relationships among the prognostic variables and other variables which are required in the mathematical solution of the prognostic equations.

The system is solved numerically as an initial value problem over a network of grid points in space. The distance between neighboring points in this network controls the detail that can be resolved in the predicted fields. Although arbitrary to some extent, this distance is more or less determined by outside factors, such as the scale size of the phenomena of interest and the available computer capacity.

It is often desirable to increase the forecast resolution over some limited area of the globe where the observational density or the nature of the problem warrants increased resolution, even though economic factors make it impractical to increase the resolution uniformly over the whole globe. In such cases, the problem is no longer a pure initial value problem, but, depending upon the numerical procedure, becomes more or less an initial boundary-value problem. There are a variety of ways in which such a problem can be handled. However, the most successful approach entails sepa-



Model density (temperature) field after six days of model time. Note the strong gradient along the dashed line. Also note the small scale distortions which quickly overwhelm the model solutions.



Solution of model identical to the above in all respects except for the incorporation of filtering. No small-scale noise is present, but the large-scale features are virtually identical. Model solutions can be extended in time without blow-up.

rate coarse-mesh and fine-mesh calculations, with the fine-mesh region nested within the coarse-mesh domain. The coarse-mesh solution is obtained for a "global" domain without artificial lateral boundaries and serves to supply the necessary boundary information for a solution with a fine-mesh grid over a limited area of the globe. The principal difficulty with this approach concerns the choice of proper boundary conditions for the particular system of equations. This problem, while serious, appears amenable to treatment and the nested-domain approach seems fundamentally simpler for routine application than the variable-grid approach.

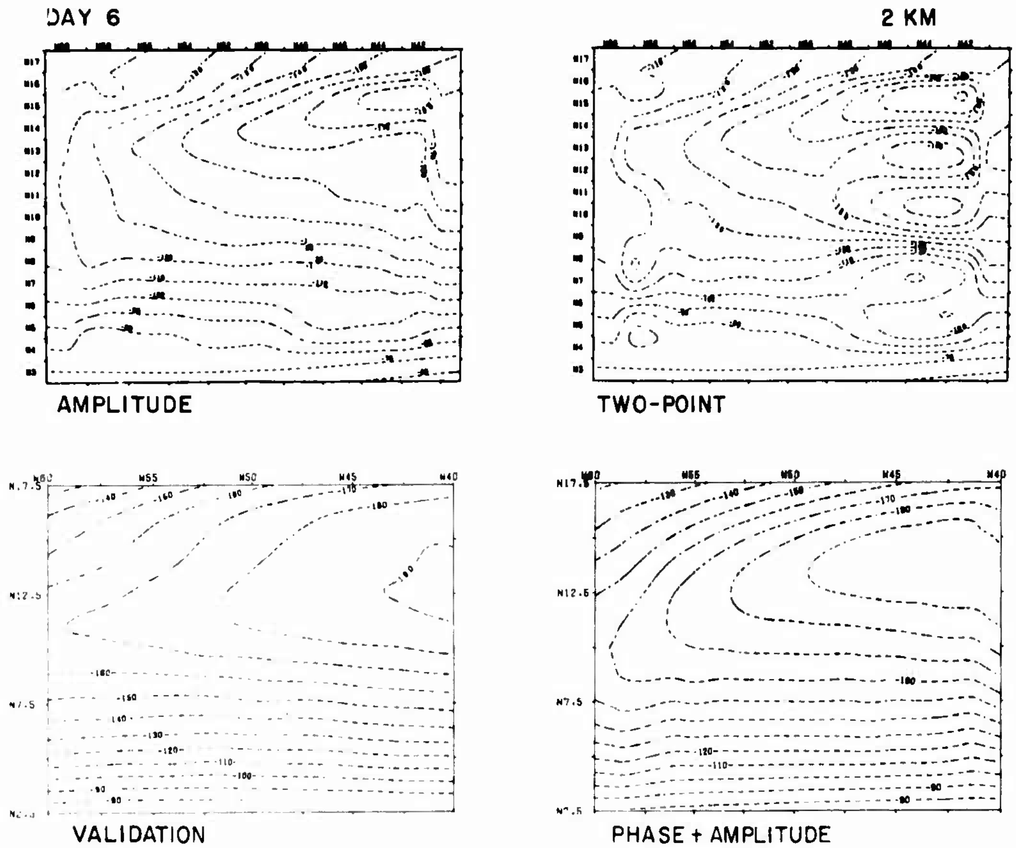
The choice of proper boundary conditions for the nested region has been extensively examined for simple, linearized hyperbolic systems. The solution should depend continuously upon the boundary data so that a small change in a boundary value should have only an appropriately small effect on the solution. However, in the finite-difference formulation of the typical NWP primitive equations, any difference between the prescribed boundary conditions and the correct boundary conditions will generate gravity waves and, although the errors may remain bounded, the solutions will be incorrect. If the differences between the prescribed and correct boundary conditions are large, nonlinear effects may generate real disturbances which could grow rapidly. A correct set of boundary conditions should specify the normal velocity and temperature in such a way that the outward propagating components are not hindered in passing out of the region. However, this is not practicable for a multilevel model.

Even if it were possible to define the "correct" boundary conditions for a realistic limited-area problem, in practice, the boundary conditions would at the very least contain truncation errors because they would be determined not from continuous fields but from a small number of point values. However, real boundary errors will be more severe in the finite-difference solution since the proper boundary conditions cannot be defined for realistic problems, and at best one can apply boundary conditions which are appropriate for much simpler problems. Also, obtaining the proper boundary conditions for even the simpler problems is likely to involve computational and programming complexities.

A certain amount of boundary error is inevitable in realistic, three-dimensional problems (regardless of the choice of boundary conditions and the method used to obtain them). To keep the errors to a minimum, a high-order interpolation procedure was devised for supplying time-dependent boundary values in a fine-mesh limited-area model. The interpolation is performed on a "global" coarse-mesh solution which is run concurrently with, but independent of the fine-mesh solution.

The interpolation operator used to supply the fine-mesh initial and boundary information from the coarse-mesh solution should satisfy certain criteria. The operator should damp two-grid-interval noise, but not longer, meteorologically significant variations. Furthermore, since much of the error introduced by interpolation is due to phase error, the ideal interpolation operator is one which removes two-grid interval waves, restores the amplitude of larger waves and corrects the phase shift produced by the customary interpolation procedures. Using principles similar to those discussed above for the scale-dependent filter, we have designed an interpolation operator with precisely these ideal characteristics. It is highly scale dependent (more scale dependent than the ideal filter) and corrects for phase error. The use of this interpolation operator in a fine-mesh limited area, multilevel, primitive equation model has been shown to provide suppression of much of the gravity wave noise generated by the artificial lateral boundaries.

Boundary Layer Prediction Model: We have completed an effort undertaken to investigate the Air Force Global Weather Central's Boundary Layer Model (designa-



Fine-mesh limited area zonal wind field after six days of integration. Boundary information is supplied by interpolation from global coarse-mesh solution. "Two-point" uses two-point linear interpolation and suffers from severe boundary noise. "Amplitude" uses amplitude restoring interpolation which improves the solution. "Phase and Amplitude" makes use of phase and amplitude restoring interpolation, which yields excellent results in comparison with the "Validation" solution.

ted as AFGWC-BLM hereafter) for possible improvement in its forecasts. Because of operational constraints at AFGWC, we sought only improvements that would require neither additional capacity in the central memory nor extra computer time. Furthermore, we limited our consideration to modifications that could be implemented in the prognostic phase of the model.

Effects of various modifications of AFGWC-BLM on forecasts were analyzed by comparing characteristics of the resulting forecast errors obtained on synoptic samples that were collected randomly during the period between April 1975 and December 1976. The merit of a modification was inferred from these analyses. Because of the amounts of time and cost involved in the production and analysis of forecasts, the study was carried out in a number of stages in which the modifications were imposed sequentially on the basis of inferences drawn in earlier stages of the investigation. Sixty-three synoptic samples were divided into two groups of about the same size. All the proposed modifications were first run on the first group, but only those that were deemed worth further investigation were tried on the second group in order to test the validity of the inferences drawn from analyses of the first group.

The study of modifications was carried out in three stages, each of which addressed one particular aspect of the model. They are: 1) computational resolution; 2) vertical structure; and 3) humidity forecasts. In computational resolution, it was found that doubling the size of the time step produced little adverse effect on the forecast accuracy, while doubling the interval of the horizontal grid resulted in significantly larger forecast errors. The effects of modifications on the vertical structure were measured by comparing the temperature forecast errors. Of the three factors considered — namely, the estimation of eddy diffusivity, the hydrostatic equation, and the vertical differencing, — only the modification of eddy diffusivity produced statistically significant improvement in forecast accuracy. A modification in the estimation of the surface specific humidity was contrived to preserve the advantage gained by the new eddy diffusivity without degrading the accuracy of the accompanying humidity forecasts.

On the basis of these experimental results, AFGL has suggested to AFGWC that AFGWC carry out a further study on the effects of the new diffusivity and the new surface specific humidity. These alternatives are both simpler in concept and less laborious in computation than those currently employed in the operational version and can be readily incorporated into it. However, we believe that extensive revisions of the model are necessary to achieve a large increase in forecast accuracy. Such a reorganization must be made by consideration of both the diagnostic and prognostic phases of the model.

CLIMATOLOGY

Air Force systems must be designed to operate in, and withstand, atmospheric extremes of known calculated risk of occurrence. Overdesign can be costly, while underdesign can cause failure and loss of life or an aborted mission. Climatological studies, therefore, are pursued to improve our knowledge of risks to Air Force equipment as well as for operation planning, thus minimizing weather effects on Air Force operations. Limitations of available meteorological observations make it necessary to develop both theoretical and empirical models to describe the structure and variability of the atmosphere. Models are being developed to improve estimates of climatic extremes, the areal extent of weather events, and the duration and recurrence probabilities of critical weather conditions.

Line-of-Sight Climatology: Many current and proposed Air Force systems use optical, infrared, and laser sensors for detection, lock-on, and tracking. Because many of these sensors cannot operate through heavy haze or clouds, there is an increased need for information on the probability of haze- or cloud-free lines of sight. Two efforts have been conducted to determine how often haze or clouds would limit operations: an aircraft in-flight observation program and the development of a cloud-free line-of-sight (CFLOS) model based on observed cloud-cover statistics.

Probabilities of clear and cloud-free lines of sight from aircraft at various flight altitudes over much of the Northern Hemisphere have been determined from more than 275,000 in-flight LOS observations. These probabilities have been published in an AFGL technical report which includes a classified addendum. This information will be valuable to designers and operators of many electro-optical systems coming into or already in the inventory. The utility and optimum deployment of these weapon systems can be estimated from a knowledge of clear and cloud-free line-of-sight statistics.

A model for estimating CFLOS probabilities has been developed by correlating cloud-cover observations with whole-sky photographs. This model, which provides CFLOS probabilities through the atmosphere for any desired elevation angle, based on cloud-cover statistics for a given location, was used to produce a series of atlases of

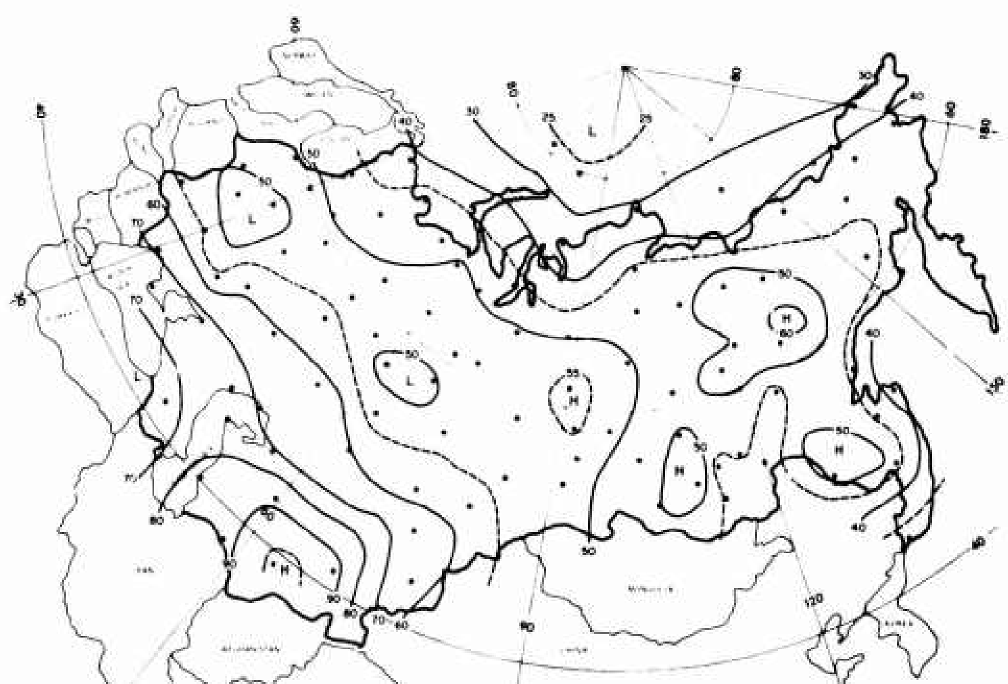
CFLOS probabilities for the USSR, the USA and Europe. A sample page from the USSR atlas is shown.

Ice particles and water droplets in clouds can erode hypersonic vehicles, and precipitation can partly or completely absorb the millimeter wavelengths often used for communications. A climatology of precipitation occurrence is being developed for determining the probability and extent of precipitation along various ray paths through the atmosphere. A three-year collection of photographs of radar scopes taken at 17 National Weather Service radar sites was completed in December 1975. The radar scope was photographed every three hours with the antenna at each of four elevation angles: 0, 15, 30, and 45 degrees.

These photographs will be used to develop a climatology of the slant range thickness of precipitation echoes. These data will provide probabilities of precipitation interference along ray paths from the surface, between two altitudes, and from any altitude out to space or to the ground.

Air Force Reference Atmospheres: Mean monthly reference atmospheres, which describe the seasonal, latitudinal and longitudinal variations in the thermodynamic properties of the atmosphere for levels up to 90 km, have been developed and published for 15-degree intervals of latitude. Specialized models, which depict the magnitude of the changes in the vertical temperature and density profiles that occur during the winter warmings of the stratosphere and mesosphere in arctic and subarctic regions, are included. Information is also provided on the day-to-day variations of density and temperature around the monthly means. These models expand and update the information contained in the U. S. Standard Atmosphere Supplements, 1966. They are intended for use by engineers in the design of aerospace systems.

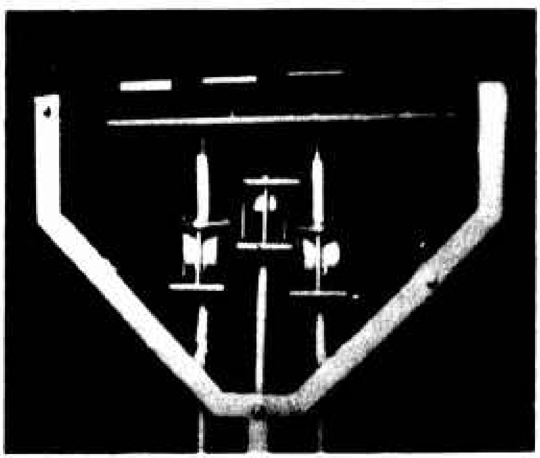
Ice Accretion: Ice accretion is an important consideration in the design and operation of Air Force surface structures, such as towers, radio antennas and radar. It is one of the few meteorological parameters



CFLOS probabilities for the USSR in July near noon (1200-1400 LST) at an elevation angle of 90 degrees.

yet to be quantitatively observed on a routine basis. In 1976, the Air Weather Service submitted a "Geophysical Requirement" to AFGL which stated the need for establishing a climatology of ice accretion to support Air Force engineers in making design trade-offs. In response to this, a program was initiated to determine the feasibility of making objective observations of ice accretion mass and thickness using a sophisticated, off-the-shelf, ice detector designed primarily for use on aircraft. The detector works by collecting the ice on an ultrasonically oscillating sensor. It is driven at its resonant frequency when dry, but accretion of ice will cause a shift in resonance corresponding to the increase in mass on the probe. After a small preset amount of ice has accumulated, the sensor is deiced.

Tests on the detector were conducted in a climatic chamber for a wide range of synoptic situations which simulate natural icing conditions. For these tests, the number of instrument deicing cycles was very highly correlated with measurements of mass and thickness on simulated structural members. Further testing of the ice detector in the natural environment will be accomplished at four locations in eastern Massachusetts during the winters of 1978-1979 and 1979-1980. At the same time, AFGL will be working with Air Weather Service in planning the deployment of the detectors at a number of stations in the Northern Hemisphere. Once a network is in place, data collected will be analyzed to determine icing design criteria.



Ice detectors and simulated structural components on a stand during the climatic chamber tests.

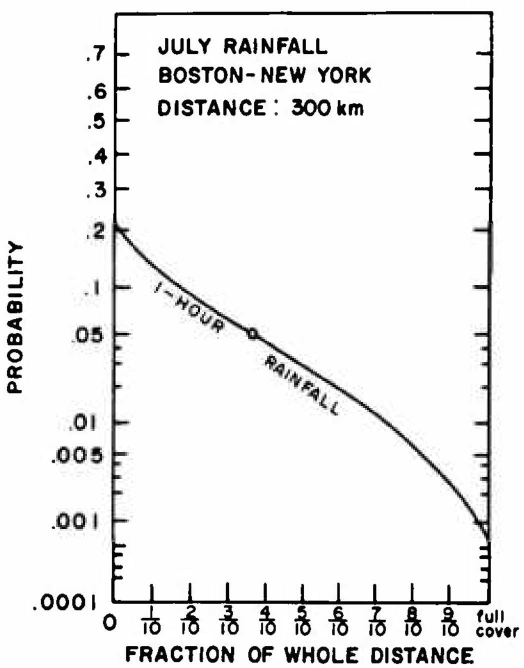
Line Coverage: If the probability of occurrence of an event at a single observation point is known, what is the corresponding probability of occurrence of the same condition everywhere along a line or a fraction of the line, or in a surrounding area or fraction thereof? There have been abundant specific examples of this basic question, many with respect to the areal coverage of rainfall.

Satellite pictures, recording as they do areal cloudiness, make possible a study of the field of view of a given area or percentage of the area. Radar has been a valuable asset for its panoramic view of precipitation within a circular area surrounding the radar site. But, generally, the archived climatological records contain single-instant observations of the weather at single-point weather stations. Rainfall amount, for example, is the amount collected at the location of the bucket or rain gauge. Area coverage or line coverage, therefore, must be obtained by a special task of data collection, or must be estimated by practical rules or models.

Previous investigations had been based on statistical models which provided answers on the frequency and duration of weather events and on the areal extent of weather conditions. Recently, a solution of the model selected for the duration of events was obtained analytically, thus providing for computer programming of problems and answers. Such answers, until recently, were only approximate, having been obtained by random number simulation.

Simulation is still the method of development for the model of areal coverage. It has provided solutions to several important problems. For example, what is the probability that a low-flying vehicle will travel free of cloud and rain particles for all or most of the crucial segment of the trip? Or what is the probability of a non-attenuating line of sight? Graphs that provide the answers to such questions on line coverage were prepared recently with the help of random number simulation.

To illustrate the usefulness of the new graphs on line coverage, suppose the problem is to investigate the likelihood of rain during one hour, in July, along all or part of the 300-km distance from Boston to New York. The diagram illustrates the use of the model. Starting at the right-hand side, it shows that the probability of simultaneous rainfall, in July, everywhere (10/10) along the 300-km distance is only 7/100 of 1%, but the probability of the condition of rainfall over at least 3/4 of the distance is nearly 1%. The probability of its occupying over 1/2 of the distance is nearly 5%, the same as the probability of its occurring at a pre-selected station. The probability of its occurring over at least 30 km, or 1/10 of the length, is up to 13%. The probability of its occurring anywhere at all, in however small an area, is 21%, which also means that there is a 79% probability of no rain in that hour anywhere along the 300-km line of travel.



One hour rainfall probability, in July, along the great circle from Boston to New York as a function of the fraction of the line occupied by rainfall. The circle indicates the single-station probability, 5%.

Joint Probabilities: For the design of equipment and the planning of some military operations, climatic risk can be estimated from probabilities of occurrence of a single weather event, such as a temperature extreme of 110 degrees, or heavy rain, at a given location. However, some Air Force missions will not succeed unless favorable weather is observed at more than one location, or at more than one point in time. In planning such missions, joint occurrences of weather events are required. A Monte Carlo technique was developed to estimate probability distributions of favorable weather within a specified area or along a line of travel. This technique has been tested on several meteorological elements and found to be effective. Another model has been developed for estimating the probability of occurrence of any given weather event jointly at two locations if the unconditional probability of the event at each location and the spatial correlation is known.

A similar model has been developed for estimating recurrence probabilities — that is, probabilities that a weather event will occur at time t and recur at time $t+\ell$. This model also yields good estimates. However, these estimates are generally not as good as the estimates of joint occurrences in space because diurnal variation is not well accounted for in the model.

Studies are under way to develop models for estimating joint occurrences of weather events at more than two locations or more than two time periods.

Stratosphere-Mesosphere Relationships: Meteorological rocket and radiosonde observations have been used to examine the decay in the coefficient of correlation between the densities at two points with increasing vertical and horizontal separation. The results of these studies have been used to prepare statistical arrays of the means and standard deviations of density at altitude intervals of 5 km, together with interlevel correlations. These arrays can be used to determine the integrated effect of density on the trajectory of reentry vehicles provided the influence coefficients for the vehicles are known. This eliminates the need for engineers and designers to fly a new design through a representative sample of individual density profiles to obtain estimates of the distribution of density effects on a particular reentry vehicle.

WEATHER MODIFICATION

Operations at most airports are hampered more by the presence of fog than by any other weather phenomenon. Likewise, the presence of low stratus clouds seriously hampers tactical and surveillance operations. The ability to disperse these types of clouds would greatly improve the Air Force's mission success probability. In recognition of the fact, AFGL has studied techniques for operational fog and stratus dispersal for several years. Recent attention has been focused on the development of an operational warm fog dispersal system using ground-based heat sources and the development of a tactical technique for supercooled stratus dispersal.

Warm Fog: During the past several years, many techniques for warm fog dispersal have been evaluated by AFGL. The studies concluded that the most promising technique for airport operations was the use of thermo-kinetic energy. As a result of AFGL's applied research effort, an engineering development program was launched in 1975. The program was managed by the Civil and Environmental Engineering Development Office, with technical support provided by AFGL. Under a separate effort, a smaller theoretical study was conducted on the possible use of radiant energy for dispersing fog and stratus.

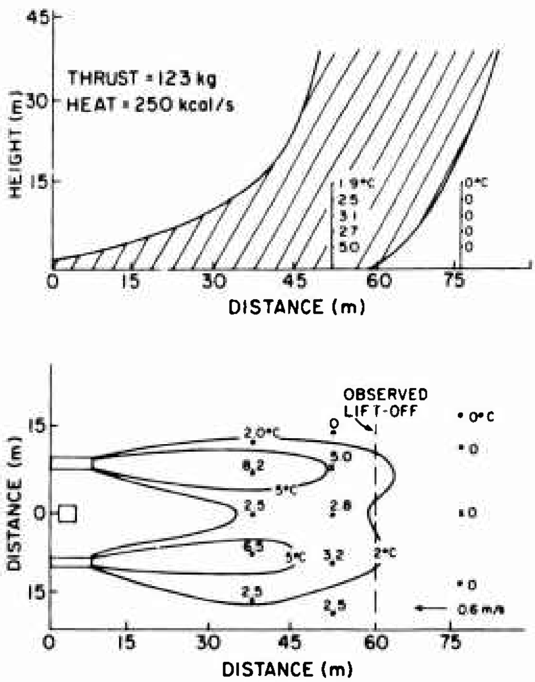
The thermo-kinetic warm fog dispersal system (WFDS) designed by AFGL has two principal components: the combustors and the controls. The combustors produce heat and provide thrust to project the heat into the target area. The controls allow remote operation and monitoring of the combustors, and automatic regulation of the heat and thrust requirements, depending on the prevailing wind and visibility conditions. The combustors are located along both sides of the approach and rollout portions of the runway. The clearing produced will allow landings to be safely completed under Category I approach conditions. This means that the visibility will be raised to 800 meters (½ mile) to a maximum depth of 75 meters (250 feet) over the approach zone and 15 meters (50 feet) over the rollout portion of the runway.

The key to an efficient and reliable WFDS is to design the combustors to produce sufficient heat and thrust for all expected wind and visibility condition. The Meteorology Division has been primarily concerned with defining the optimum combustor settings and configurations for a wide variety of meteorological conditions, and for defining the meteorological instrumentation requirements for the WFDS.

Based on earlier subscale tests and analytical modeling studies, a set of combustor specifications was drawn up. The combustors were designed under contract, and a single runway and an approach zone combustor were fabricated and tested for reliability. The combustors each produce two exhaust flows of heated air. Each unit consists of a central diesel engine with propellors at each end to produce the combustion air and the thrust air. The air is heated as it passes by a burner located in front of each propellor and then enters an elbow, where it is turned 90 degrees toward the runway.

Tests were conducted at the contractor's test facility in clear air to determine the plume profile under a variety of heat, thrust and wind conditions. It was assumed that a temperature rise of 2 to 3 degrees C is required for clearing fog. The optimum heat and thrust settings were then determined for a variety of wind conditions. The test results indicated relatively close agreement with the previous experimental and theoretical studies. However, the plume trajectory appeared to be less sensitive to wind and heat than previous studies had indicated.

Since the WFDS is required to clear up to depths of 75 meters for a Category I approach, a knowledge of the winds up to 75 meters would be beneficial in controlling the position of the heat plumes. Consequently,



The vertical and horizontal cross-sections of the heat plume from a dual outlet, runway WFDS combustor. The vertical cross-section was derived from a smoke tracer. The horizontal cross-section was determined from an array of thermistors at 3 meters above ground.

an evaluation was made of two indirect wind measuring probes: the acoustic Doppler wind sounder (ADWS) developed by the National Oceanic and Atmospheric Administration's (NOAA) Wave Propagation Laboratory, and the laser Doppler velocimeter (LDV) developed by Lockheed. Both the ADWS and the LDV were tested at the AFGL Weather Test Facility at Otis AFB, Massachusetts, in September 1976 and again in September 1977. Both instruments measure the wind by utilizing the Doppler shifting of backscattered energy from moving targets. In the case of the ADWS, the scattering is by inhomogeneities in the index of refraction; with the LDV, it is by atmospheric aerosols. The data from the two probes were compared with the winds measured by sensors mounted at different levels on a 60-meter tower. The indirect measurements compared quite favorably with the direct measurements in both fog and clear air. Either system would, therefore, be suitable for incorporation into the WFDS control system.

In recent years, various scientists have suggested the use of radiant energy for dispersing fog or stratus. In 1977, an in-house theoretical study was conducted to determine the feasibility of such an approach. In the study, the source of microwave power was considered to be either ground-based or airborne. For the ground-based case, the microwave beam was taken as parallel to the ground and along the runway, providing a direct source of microwave power for heating the fog. For the airborne case, the beam was taken as perpendicular to the ground, the heating of the ground by the microwave beam providing a source of infrared power for dissipating the fog. The study showed that, for either case, very large power densities, well above the personal safety limit of 100 watts/m^2 used in the United States, would be required to dissipate the fog in a time of about ten minutes. If the power density is taken as 100 watts/m^2, a very long time, that is, many hours would be required to dissipate the fog. In addition, because of the high cost of electrical energy, the large amount of energy required for a typical airport fog (about 3×10^{11} joules) makes the scheme prohibitively expensive.

Supercooled Stratus: Supercooled stratus dispersal tests were conducted in February 1977 to determine the feasibility of producing clearings over a predetermined ground target using a small aircraft as the seeding platform. The requirement that a small aircraft be used virtually eliminated the possibility of using dry ice, which has been the standard seeding material for many years. Dry ice requires a rather large dispenser, which can only be carried on larger aircraft, such as a C-130. Silver iodide flares, on the other hand, require only a simple dispenser which can be mounted under the wing or fuselage of a small airplane. Other advantages of silver iodide flares are reliability, simplicity, minimal logistic requirements, and suitability for advanced delivery systems. The silver iodide flares are ejected from an aircraft and fall between 600 to 1800 meters before being totally consumed in the combustion process. The smoke from burning pyrotechnic contains silver iodide crystals which serve as ice nuclei. The manufactured pyrotechnic grains contain a very small amount of chlorine. Addition of the chlorine produces greater nucleation effectiveness, especially at warmer temperatures.

Clearing produced in stratus clouds, 730 meters in depth, 30 minutes after dispensing 11 flares (220 gm AgI) along a 1.8 km line.

Field tests were conducted in northern Michigan, with the base of operations at Traverse City. This location was chosen because of the frequency of supercooled stratus in this area, airspace availability, terrain and logistic support. The primary purpose of the tests was to determine the feasibility of targeting the clearing over a predetermined ground target. Another objective was to optimize the seeding rates and patterns in terms of the quality of the clearing produced.

Two aircraft were used in the tests. One seeded the cloud at cloud top, and the other served as an observation and command platform at higher altitude. Photographs taken from the observation aircraft served as the primary data and evaluation tool. Photogrammetric analysis of selected photographs allowed measurement of horizontal dimensions of the clearings. Ten missions were flown, resulting in 15 tests.

Five major conclusions were derived from the test data. First, it was not particularly difficult to target the clearings, given accurate wind measurements. Second, the quality of the clearings (in terms of visibility) was not as good, as hoped, although it did appear to correspond with previous studies. In most cases, it was possible to observe the ground when looking vertically down. However, it was not generally possible to see the ground along a slanted line of sight. Third, the silver iodide pyrotechnic seeding system was capable of producing clearings very similar to those reported in earlier studies and appears to be a suitable choice for tactical use. Fourth, clearings were produced at temperatures as warm as −8 degrees C and in clouds up to 4,000 feet thick. Finally, clearings up to 18 km in diameter were produced from seeding patterns measuring 4 km by 5 km.

In addition to the field tests, a one-dimensional mathematical model of the growth of ice crystals in supercooled clouds was examined in detail and a sensitivity analysis was performed. Critical parameters include seeding rate, temperature, cloud depth, liquid water content, drop size and updraft velocities. When reasonable values of cloud physics parameters and known values of the seeding rates, minimum temperatures, and cloud depth were used in the model, reasonable agreement between the theoretical and observed rates of cloud dissipation was obtained.

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The AFGL transportable absolute gravity system in its most recent configuration. Packed for shipment in nine boxes, the system weighs about 700 kg. A measurement takes 2 or 3 days to obtain a precision of 0.05 μm.sec^{-2} to .15 μm.sec^{-2} (5 to 15 μgal).

VI TERRESTRIAL SCIENCES DIVISION

The Terrestrial Sciences Division conducts research on the properties of the earth's surface, subsurface, and near atmosphere using the disciplines of seismology, geology, geodesy, and gravity. This research supports the deployment, operation, and delivery of Air Force weapons with particular emphasis on strategic systems. Instrumentation is designed and produced to measure geophysical phenomena worldwide at varying scales and accuracy levels to meet specific needs. Field work is conducted whenever and wherever necessary. Instrumentation is mounted on a variety of test beds designed to operate on land, in the air, or in space, and data are collected where the organization's experience and theory suggest the need. Theoretical models of geophysical phenomena are developed and cast into a quantitative form for comparisons with observations. Tested mathematical models of geophysical phenomena are produced in a variety of formats that are useful in various applications.

During the reporting period work has been conducted on automated position and azimuth determination, lunar laser ranging, very long baseline interferometry, absolute gravimetry, satellite altimetry, and geopotential modeling. Effort has also been applied in crustal motion research, the development of tiltmeter technology for Air Force geophysical applications, and the determination of specific and detailed aspects of the motion environment of a midcontinent missile silo.

GEODESY AND GRAVITY

Geodesy is concerned with the size, shape, and mass distribution of the earth. Accurate geodetic information is a necessary foundation for the accurate determination of position, distance, and direction for launch sites, tracking sensors, and targets. The geodetic and gravimetric parameters for the earth and geodetic information for positioning not only form the structural framework for mapping, charting and navigational aids, but are also direct data inputs for missile inertial guidance systems. Current geodetic information is inadequate to meet the requirements of future USAF weapon systems.

The Division conducts continuing research and development programs in geometric geodesy and in physical geodesy (or gravity). These programs are directed toward improving the fundamental knowledge of the earth's size, shape, gravity field and the techniques used for determining position, distance, and direction on the earth's surface and in terrestrial and inertial three-dimensional coordinate systems.

In Satellite Radar Altimeter and Gravity Gradiometer Programs, AFGL participates and cooperates with the Defense Mapping Agency, the Army, the Navy, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, other civilian agencies, and academic observatories. The Terrestrial Sciences Division also participates with the International Gravity Commission in the development of a worldwide gravity reference network. A worldwide system of earth-tide profiles is being established in cooperation with the International Center for Earth Tides, Brussels, Belgium.

Automated Position Determination: Geodesy is concerned not only with positioning but also with the orientation of a site in inertial space. The conventional inertial reference standards for inertial orientation are the stars, and the usual orientation angles are known as astronomic latitude, longitude, and azimuth. Other inertial reference standards besides the stars exist (the lunar orbit and gyroscopes, for instance) but currently the stars are the best and most widely used inertial reference standards available to geodesists.

Studies show that the human being can be the largest error source in astronomic position determination. Therefore, all of AFGL's position determining, transferring, and monitoring experiments deal with various phases of automating one or more of the components involved in this very specialized type of position determination.

The present research and development program of the Geodesy and Gravity Branch in automated positioning determination encompasses: the determination of azimuth or a reference direction that can serve as a precise azimuth reference; the transfer of azimuths and monitoring of azimuths to determine their stability; and experimentation in methods of measuring refraction at the point of observation.

To determine azimuth or a reference direction based on the precise location of the earth's rotational axis, AFGL sponsors two contractor experiments which use ring lasers or fiber optics in ring interferometer systems to detect the earth's rotation. Both of these programs are directed towards the development of optical ring gyroscopes to the point where they will be geodetically and geophysically significant instruments in finding the local direction of the earth's rotational axis. Given this axis, the precise value of astronomic latitude and direction of north, south, east, or west can be determined.

Another AFGL experiment in azimuth determination consists of an effort by the University of Hawaii to design, construct, and test a device that automatically transfers an azimuth reference. This experiment will produce a completely automated device for turning highly precise, repeatable azimuth reference angles. The device consists of a catadioptric telescope mounted on a computer-controlled indexing table that has a silicon photo-diode linear sensor in the focal plane for use as a vernier aiming device. The indexing table automatically positions the telescope in azimuth by means of the computer controller that drives the indexing table in 1-degree increments and uses the movable linear photo-diode to position a target within one arc-second of the optical axis of the telescope. The instrument is leveled with an electronic capacitance level, eliminating the need for manual fine adjustments. After initial settings of the

Azimuth transfer device showing, from right to left: catadioptric telescope mounted on indexing table; electronic controls; computer controller and data recording unit.

telescope on the azimuth reference marker, all horizontal movements are controlled and recorded with the computer controller. The azimuth transfer head has been completed and is now being tested at the National Geodetic Survey of the National Oceanic and Atmospheric Administration.

An AFGL azimuth monitoring experiment is designed to employ the differing characteristics of plane mirrors and prismatic reflectors for monitoring rotational and translational movements of an azimuth reference or any other reference station whose positional stability must be closely monitored to meet Air Force requirements. The experiment uses a small He-Ne laser as its light source. The light is split and transmitted into two mirrors at the site to be monitored. One of these mirrors is a plane mirror, the other a prismatic retroreflector. Each mirror is so aligned that it will return its image of the laser to a positional monitor consisting of a silicon diode junction barrier capable of monitoring the movement of the centroid of the return image in two axes. Rotational movements are discriminated from translational movements by comparing the images reflected from the plane mirror and retroreflector. A constant record of the fluctuations of the position of the centroids of the two returning images is recorded on magnetic tape.

AFGL sponsors a program to develop a field device for real time measurement of astronomic refraction. The two-color refractometer measures very precisely the differential refraction between the blue and red portions of the image of the star. The total refraction is calculated from the measured differential refraction. The next phase will consist of the de lopment of a small scale instrument capable of being taken to geodetic survey sites where the two-color observations will be used to determine astronomic refraction at the point of survey.

Laser Ranging and Radio Interferometry: More accurate distance measurements of the moon and high altitude artificial satellites made by earth-based laser ranging telescopes, and accurate angular measurements made by radio interferometers, may soon produce significant advances in geodesy and geodynamics. Measurements accurate to a few centimeters will allow us to measure solid-earth tides and continental drift, as well as to improve our knowledge of variations in the earth's rotation rate and polar motion.

AFGL participated in the NASA Lunar Laser Ranging Experiment. Since 1970, more than 2400 range measurements have been made between the McDonald Observatory in Texas and four of the retroreflectors placed on the moon by the Apollo and Soviet space missions. AFGL scientists have analyzed these data, using the Planetary Ephemeris Program, a large computer program developed under contract by AFGL and other DoD agencies. The data analysis has significantly improved our knowledge of: the lunar orbit and its physical libration, the coordinates of the McDonald Observatory, the principal term in the earth's gravity field, and day-to-day variations in the earth's rotation rate.

AFGL's analysis of lunar ranging data also produced the first verification of the Principle of Equivalence for massive bodies, the cornerstone of Einstein's General Theory of Relativity. This significant scientific achievement was reported in both academic and popular publications.

The AFGL lunar telescope, operated in Arizona between 1968 and 1972, has been refurbished by Australian geodesists and is now in operation near Canberra. Laser ranges from a southern hemisphere observatory allow analyses of the lunar data for separate determinations of variations in the earth's rotation and movement of the pole.

Complementing the lunar ranging experiment is an extensive NASA-DoD program for laser ranging to earth satellites, a technique pioneered by AFGL scientists in the early 1960s.

The launch of the high-altitude, high-mass-density Laser Geodetic Satellite (LAGEOS) in 1976 has provided a target whose orbit is relatively free from the effects of atmospheric drag and small-scale variations in the earth's gravity field, allowing range measurements for geodesy accurate to 5 to 10 cm.

Another technique that has been used for geodetic measurements is very-long-baseline interferometry (VLBI). VLBI determines the three-dimensional position of one radio telescope relative to another using observations of distant radio sources such as quasars. AFGL, together with NASA, the National Science Foundation, and the National Geodetic Survey, is supporting the development of a very accurate VLBI system. Geodetic positions have been determined within a few centimeters over continental distances and a few millimeters over a distance of one kilometer by analyses of data already obtained. Variations in earth rotation have also been determined from VLBI data.

Many geodetic parameters, such as the coordinates of observing stations and the earth's instantaneous pole of rotation, can be determined most efficiently by combining several types of data during analyses. The Planetary Ephemeris Program will be used by investigators under AFGL contract to perform simultaneous least squares solutions for a large number of parameters, using lunar laser ranging, satellite laser ranging, and VLBI data.

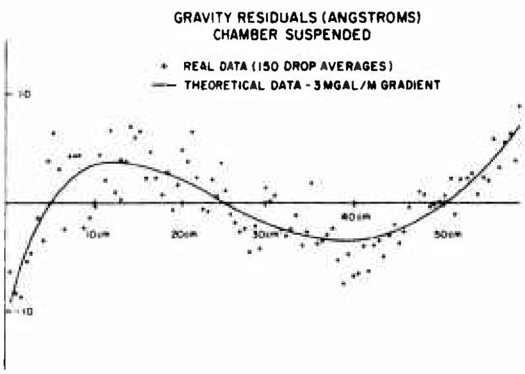
Absolute Gravimetry: The Terrestrial Sciences Division's program in absolute gravity is divided into three main areas: support of outside research into measurement techniques and of comparative measurements by other absolute instruments; the study of the physics of the measurement techniques and the development of new instrumentation; and measurements in the laboratory and at selected field sites with the AFGL transportable system.

The outside work supported by AFGL includes that of the Joint Institute for Laboratory Astrophysics in Boulder, Colorado. AFGL is supporting the development of a novel system for the isolation of a reference reflector in an interferometer type of absolute gravity instrument. This system, which uses an electro-mechanical feedback system to synthesize a very long period vertical mass-spring support, is being designed and built into a package that will be capable of directly supporting the reference reflector on a gravity instrument.

AFGL supported a six week visit by a team of Italian scientists who brought with them the transportable absolute gravity measurement system developed by the Istituto di Metrologia "G. Colonetti" of Turin, Italy, with the cooperation of the International Bureau of Weights and Measures. Gravity was measured at six sites: Hanscom AFB, Mass.; Denver, Colo.; Holloman

AFB, N. Mex.; San Francisco, Calif.; Bismarck, N. Dak.; and Miami, Fla. The system had a mass of about 1500 kg when packaged for air transport. The work included a final remeasurement at Hanscom AFB. The uncertainty obtained was about ten parts in a billion at most sites.

The AFGL instrumentation can make quantitative determination of small effects on the measured acceleration of gravity. Effects caused by the gravity gradient and air resistance can be removed from the final value, using empirical determinations rather than theoretical corrections. Knowledge of the physics behind the measurement techniques will result in significant improvements in future instruments of this type.



The results of averaging data from 150 drops with the chamber on an isolation system. The solid line is the result of subjecting synthetic data, with a 3 μm/sec^2/m gradient included, to the same least-squares analysis. Thus, most of the systematic appearance, if not all, is caused by the vertical gradient.

AFGL is investigating new developments in electronics and other areas to solve some of the current problems with this kind of instrumentation. Several techniques for simplifying system operation are currently being employed at AFGL. The system is completely automated and data are analyzed and corrected for gravity tides in real time. Optical and mechanical alignment are simplified over previous systems, and self-checks on timing accuracy can be performed independent of a gravity measurement.

Measurements are currently being made with a system that incorporates the vacuum chamber from the first generation instrument and uses a control system and support base (with optics) built at AFGL. The method used for measurement is to drop one reflector of a two-beam Michelson interferometer and determine the distance fallen in known time intervals by direct measurements of interference fringes.

The vacuum chamber allows a 60 cm free fall path. A smaller vacuum pump is used, and the pump magnetic field is reduced considerably from the earlier system. An "old-fashioned", simple, free-fall technique is used. The system has a total mass of about 700 kg when packed for air transport, and it is contained in nine boxes that can be handled by one or two people.

The first field measurements were made in May 1978, approximately 6 months after the decision to convert the old vacuum chamber for use with the new system. At the time of that field trip, a computation technique that used 150 time measurements from 3 different positions in the free fall path was being used1 This trip was very valuable in demonstrating the capabilities of the system, and in leading to an improved computational technique for data reduction.

In this new method the time and distance data are fit with a least-squares technique to the formula for uniform acceleration. The results obtained from this least-squares fit are: the acceleration of gravity; the initial velocity of the dropped reflector and the initial position of the dropped reflector; and a table of residuals for each drop. The residuals for each position in the path can be averaged and then plotted as a function of position. These residuals represent the deviation of the relative path difference between the reference reflector and the freely falling reflector from what it would be if the reference reflector were not accelerating at all, and the free falling reflector were accelerating uniformly with the acceleration of gravity. The chamber was also isolated from the reference reflector and the rest of the optics by placing it on a separate vibration isolation system.

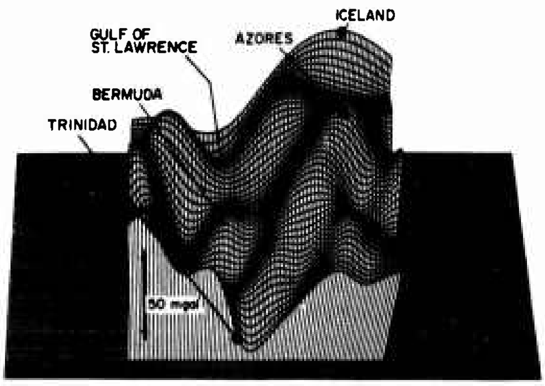
The most recent value obtained at AFGL is: 980378.673± .007 milligal (one milligal = 10^{-3} cm/sec^2). This value is only 0.002 mgal different from the average of measurements obtained in 1968 and 1969 with the first generation AFCRL (Hammond-Faller) system. This demonstrates a remarkable stability in the value of gravity at the Haskell Observatory over a ten year period of time.

Satellite Altimetry: One of the major tasks of geodesy is the determination of the gravity field over the entire earth. Prior to the advent of satellites, global representation of gravity was severely hampered by sparse or poorly distributed gravimetric measurements in the oceans. With the launching of the GEOS-3 satellite in 1976, however, enormous improvements have been achieved in our knowledge of the ocean's gravity field. The radar altimeter readings from GEOS-3 can be used to determine the shape of the ocean's surface with great accuracy, leading to important applications not only in geodesy, but also in geophysics and oceanography.

If the earth were all water, right to its center, mean sea level would be a simple geometrical figure, namely, a spheroid that is closely approximated by an ellipsoid of revolution. However, the earth is largely solid and supports density variations in continental ajeas and under oceans. These density variations cause mean sea level to vary by scores of meters from an ideal or reference ellipsoid. The irregular, smooth surface, called the geoid, formed by the extension of mean sea level throughout the earth is a fundamental reference surface in geodesy. Separations of the geoid above or below the reference ellipsoid are dependent on the variation of the earth's gravity field. This relationship has been a principal topic of investigation by geodesists, who have devised a means for determining the ellipsoid-geoid separations from surface gravimetric measurements. Now, GEOS-3 satellite altimetry can also be used to derive ellipsoid-geoid separations and, thus, the gravity field over the oceans with great accuracy.

The GEOS-3 radar altimeter is designed to measure the satellite's distance above sea level to a fraction of a meter. If the satellite's orbit can be independently established with 1 m accuracy, the determination of the shape of the mean sea level is a straightforward procedure. However, standard global tracking nets cannot achieve 1 m orbital accuracies, so the high precision requires denser nets or other advanced schemes.

At AFGL, the approach to satellite altimetry has been to assume that ground tracking is only good enough to achieve orbital accuracies of about 20 m. If we knew the position and velocity of the satellite at any epoch and integrated the satellite motion over a short arc (less than one quarter of a revolution), we could recover the position of the satellite to within about 1 m over the entire arc. Although the position and velocity of the satellite on the short arc are not known with adequate precision, we can refine our knowledge of these quantities by



NORTH ATLANTIC GRAVITY ANOMALIES
FROM GEOS-3 ALTIMETRY

Perspective diagram of gravity anomaly surface in the North Atlantic. Vertical scale is greatly exaggerated.

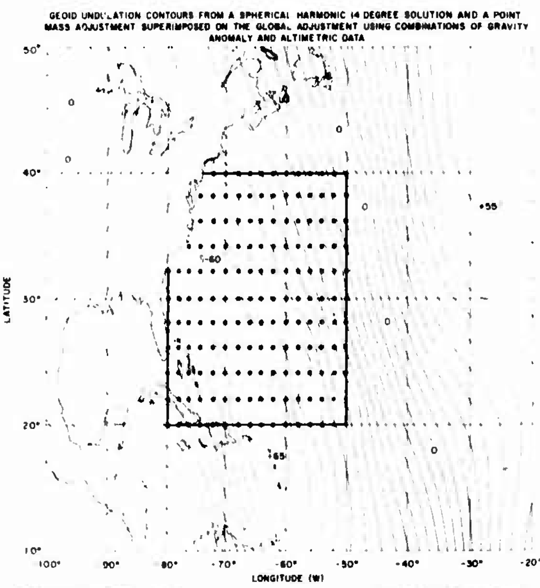
comparing altitudes from a number of independent, interlocking short arcs and improve our ability to determine the short arcs. Where two short arcs cross, the difference in measured altitudes to sea level is the vertical distance between the two arcs. The vertical interorbit ties provide a rather tight interlocking of a net of arcs, particularly in the important vertical direction. Subtracting the altimeter measurements from this net gives, finally, the shape of the ocean surface. To appreciate the magnitude of this computational task, one must remember that many thousands of GEOS tracks are available, containing more than one million altimetric values.

Initial AFGL efforts to exploit GEOS-3 data produced the computer program "Short Arc Reduction of Radar Altimetry" (SARRA). Because of the large number of measurements available, the North Atlantic and Indian Oceans received particular attention. Using only a portion of the available data (416 tracks) the SARRA reduction showed that geoid heights could be determined from the altimeter data to an accuracy near the meter level. A final version of this program was delivered to the Defense Mapping Agency Aerospace Center for application in operational problems.

Further research led to the development of SAGG (Satellite Altimetry and Ground Gravity), which utilizes altimetry augmented by surface gravity measurements and leads to a more accurate global solution, especially over land areas where altimetry cannot be used.

The most recent research at AFGL has led to a further refinement in SAGG, the point mass technique. Insertion of point masses in areas where detailed gravimetry or altimetry already exist can add fine detail to a geopotential model based on spherical harmonic coefficients. As a result, the short-wavelength variations in the geoid can be closely examined in a limited area without distorting the long-wavelength features. Although comparable results might be attained by solely utilizing harmonic coefficients, the point mass approach offers a considerable advantage in economy and flexibility, an important consideration when large amounts of data must be processed.

A new satellite, SEASAT-1, with an improved altimeter accurate to 10 cm, was launched in 1978. SEASAT-1 permits extension of the altimetry measurements to 72 degrees north and south latitudes, denser global measurements, and increased accuracy. Although a power faulure caused SEASAT-1 to cease transmitting after several months of operation, one global data set has been acquired. These data can easily be merged with existing GEOS-3 information in the short-arc solution so that even hlgher geoid accuracies will be attained.



Black-bordered rectangle in Atlantic Ocean contains grid of inserted point masses. Increased short-wavelength detail is evident from comparison of contours within and outside point mass area.

Present levels of observational accuracy make satellite altimetry much more sensitive to the shape of the earth than gravimetry; a 1 m rms geoid height over an area of 1 square degree tells much more about the shape of the earth than the same square with a 3 mgal rms gravity anomaly. Because this relative information content applies to the description of the earth's gravity field as well, satellite altimetry will make significant contributions to gravity mapping.

Advanced Adjustment Techniques for Gravity Field Modeling: Geopotential models of regional and of global extent have been developed. The simplest approach is the standard linear least-squares method, which solves for an arbitrarily chosen set of parameters (for instance, the coefficients of a truncated sphericai harmonic expansion) from a collection of measurements whose relative weights are assigned. Linear least-squares methods involving classical integral formulas are applicable when homogeneous, regularly distributed, and dense data coverage is available. With the advent of modern techniques for gravity measurements — satellite orbital analyses, satellite altimetry, satellite-to-satellite tracking, and, eventually, gravity gradiometry — an immense amount of information regarding the earth's gravity field at different levels is provided. However, the data are not uniformly distributed over the earth, are heterogeneous, and contain errors of various types and magnitude. Collocation is a refined and sophisticated method to handle such complicated problems.

The least-squares collocation takes into account the covariances between the observations and the cross-covariances between the unknowns and the observations. Therefore, analytical covariance functions must be developed. AFGL theoretical and experimental efforts in this area include: the theory and application of least-squares collocation; the theory and development of covariance functions; and application of collocation for various combination and gravity data-reduction problems. These include the combination of satellite altimetry with airborne gradiometry and satellite-to-satellite tracking for the recovery of gravity anomalies on the surface of the earth.

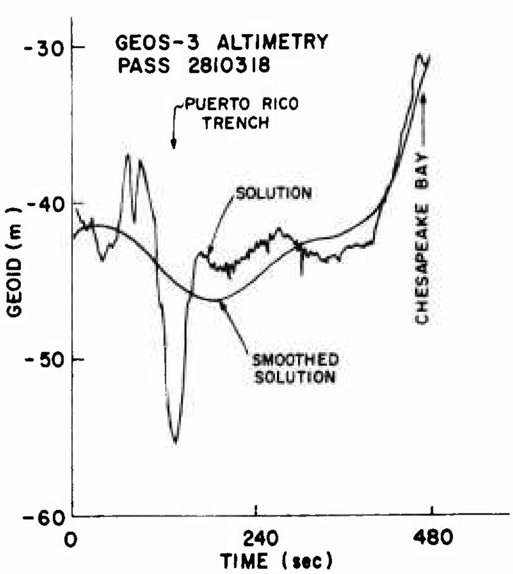
Although collocation has a theoretical elegance, it is burdened by computational difficulties because a pure collocation adjustment requires the inversion of a matrix of order equal to the number of observations; a conventional least-squares adjustment requires the inversion of a matrix of order equal to the number of unknowns. Other generalized least-squares collocation models have been investigated and compared with conventional collocation. In these techniques the order of the matrix to be inverted is equal to the number of unknowns instead of to the number of the observations. The adjustment is computationally almost as simple as for ordinary least-squares adjustment.

A priori covariance functions are required for generalized least-squares adjustments (collocation). For this reason, the covariance functions of physical geodesy have been investigated. In studying the morphology of gravity anomaly covariance functions, the properties of isotropy, harmonicity, and positive definiteness are assumed; such functions are conveniently specified by three essential parameters: variance, correlation distance, and a curvature parameter such as the variance of the horizontal gradient. An AFGL contractor demonstrated that adopting a spurious covariance function has only a relatively minor effect in the results of a collocation adjustment, but it does have a significant effect in changing the estimated accuracies of the results.

Two models were derived for the degree variances of global covariance functions and they are compatible with a 200 E^2 horizontal gravity gradient variance, (1E = 1 mgal/10 km) the GEM-9 (Goddard Earth Model 9) geopotential coefficients (derived from satellite dynamics), and point and mean gravity anomaly variances. Bucubic spline functions were also used to approximate covariance functions to improve the speed of collocation adjustments. Anisotropic and nonstationary covariance functions have also been used for the adjustment and prediction of geopotential data. Where appropriate, the results of these operations are superior to operations assuming isotropic and stationary statistics. Integrals for the upward continuation of gravity anomaly covariance functions for spherical and flat earth formulations have been derived.

Correlations between gravity anomalies and other geophysical variables have long been used by geophysicists to model the earth's structure from gravity measurements. Recently there has been increasing interest in the inverse process: estimating gravity anomalies from other geophysical observables. Models were derived for the cross-covariance functions between topography, gravity anomalies, and density variations within the earth. No correlation was found between gravity anomalies and topography on a global scale, but on a scale of the order of 5 degrees by 5 degrees, it was found that theje are significant correlations for 30 percent of the world, mostly over the continents.

Techniques for modeling from terrestrial gravity data and satellite dynamics were reviewed. Studies were conducted to assess the errors due to the disturbing topography



Geoid profile from SARRA reduction along GEOS-3 track in Atlantic Ocean.

in gravity anomaly downward and upward continuation. A mathematical technique was developed for the efficient combination of various types of physical geodetic data into a uniform gravity field model. The methodsuses frequency domain techniques. Matched asymptotic expansions are used to develop improved flat earth approximations, determine regions of convergence, and match global and local gravity models.

A rigorous theory for the combination of airborne gradiometer and accelerometer measurements was derived for local and regional geopotential models. An accuracy and simulation study was performed to determine optimal point and profile configurations from aerial measurements alone and in combination with existing satellite altimetry data over ocean areas.

GEOKINETICS

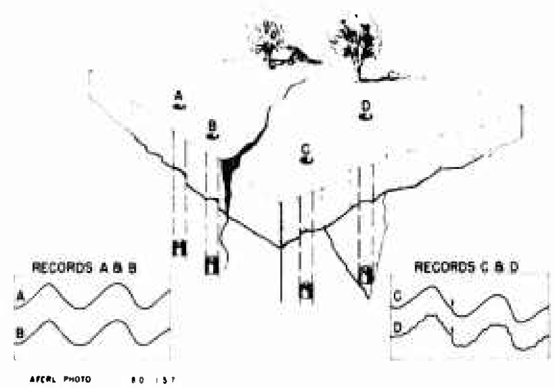
Improved technology used in the design and construction of new Air Force systems has spawned increased concern about the effects of earth motions (geokinetics) on system components. Inertial guidance instrumentation is a typical example. Each generation of gyros or accelerometers developed for use in guidance systems exceeds the sensitivity of the previous generation by an order of magnitude or more. Unfortunately, this enhancement in performance increases the sensitivity to geokinetic effects, thereby increasing the potential for errors caused by the motion environment in which the instrument must operate.

In other instances, the structural response of a facility to motion inputs may be the principal concern. If the facility must provide a relatively stable motion environment for the instrumentation or operational syszem housed in it, then the natural vibration frequencies of the structure must be well outside the bandwidth of significant input motions to prevent amplification of those motions.

The apparent solution to problems caused by earth motion effects is to develop more effective isolation or compensation techniques. However, complete knowledge of the characteristics of the motion environment and the manner in which this environment interacts with system or facility performance is needed to do this. The objective of the geokinetic research and exploratory development conducted by the Terrestrial Sciences Division is to develop this knowledge and provide it to system designers and engineers.

Crustal Motion Research: The Terrestrial Sciences Division conducts a comprehensive research program into the causes and patterns of earth motions, with emphasis on those with present or potential future impact on Air Force systems. Seismology, geology, and geotectonics are studied to predict the spatial and temporal properties of motions of the earth's crust over a wide range of frequencies Specific efforts include the measurement and interpretation of long-period deformations, the modeling of seismic motions with realistic geometric and physical properties, and the determination of seismic risk to Air Force systems and structures.

A new borehole tiltmeter array was deployed at Maynard, Mass., in early 1975; it complements a similar operational array in Bedford, Mass., 25 km to the northeast. Installation in vertical boreholes minimizes the cavity effects that have plagued earlier observations made in mines or tunnels. The Maynard instruments were emplaced at a depth of 120 m in cased holes; the Bedford array is at a depth of 20 m in uncased holes. Data from both sets of instruments, which differ in principle, design, and installation, agree within 5 percent at the semi-diurnal tidal frequencies, but show little resemblance at nontidal periods. A strong annual component ranging from 5 to 15 microradians (μrad) is present on the shallow Bedford instruments, but is not apparent on the Maynard instruments at 120 m. Tilt steps resulting from teleseisms are not present at the 10^{-8} level, in contrast to some results reported by others. One Maynard instrument, in continuous operation for 3 years, showed an extraordinarily low apparent ground tilt of 0.3μrad, although repeated geodetic leveling suggests a lesser net tilt of 0.05μrad over that interval.

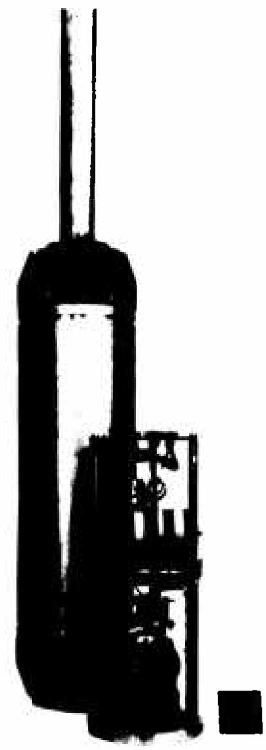


Borehole Tiltmeter Array Concept.

Also, a cluster of tiltmeters was emplaced at a depth of 3 m at Maynard to compare data with those at 120 m and with the data from the U.S. Geological Survey network straddling the San Andreas Fault in California. If satisfactory results could be obtained from the shallow cluster, considerable cost savings could be realized. However, the agreement, both among the shallow tiltmeters and with the deep tiltmeters, was poor over most of the frequency band of interest. The shallow installation was overwhelmed by meteorological effects (radiation, temperature, and precipitation) and changes in soil properties.

A powerful computer processor of lengthy time series was developed to analyze the tiltmeter data. The processor can: accept a multi-channel series with gaps and data shifts; apply scale factors; delete bad points; solve for linear trends, ocean and body tide groups, and correlations; and determine tidal ellipse parameters. Considerable progress has also been made in analyzing and comparing long-term records, using information theory. This technique is considerably more flexible than conventional least-squares, inasmuch as the probability density functions of the data (or residuals) do not have to be Gaussian. Rather, they may be specified or determined from segments of the time series itself. This method might have the potential to evoke a fundamental change in data analysis in general.

A 3-year effort began in March 1978 to measure long-term tilt and strain in the Yellowstone region of Wyoming and Montana. This area is one of moderate seismicity and has been postulated to be the surface manifestation of an upwelling plume of molten material from the earth's mantle, which should be detectable by the effects of its anomalous physical properties. A new biaxial tiltmeter, suitable for installation in 50-m boreholes, has been developed for this study. Ten of these, as well as several horizontal laser strainmeters, are being deployed at sites approximately 10 km apart and carefully selected to avoid cavity and topographic effects or permit their computation. The earth tides will be analyzed to check on the completeness of tidal theory and to verify the absence of strain-induced tilts. The variations of tilt and strain will be interpreted in terms of regional crustal structure, tectonics, and seismicity.



Borehole Biaxial Tiltmeter.

Increased emphasis on seismic wave propagation resulted from an earthquake in the Pocatello Valley (Idaho) in March 1975. The seismic waves from the earthquake caused an anomaly in some of the Minuteman guidance systems diagnostic parameters at Wing V several hundred kilometers away. Only some of the missiles were affected, forming a geographic pattern that extended through the center of the wing from northwest to southeast. A subsequent field reconnaissance revealed that the missiles sited on plateaus were perturbed, while those in the lower-lying valleys were not. Normally, ground motion recorded from an earthquake of this magnitude at this distance would not produce the anomalies observed. This suggested that the motions were controlled by the geology or topography, through focusing or some similar enhancement mechanism. To investigate this possibility, two seismic stations were established in geologically contrasting areas within Wing V for the purpose of assessing ground motion transfer attributes peculiar to the area. The stations were in operation over the course of a year and recorded both earthquake and explosive teleseismic events. A contract research effort was initiated to numerically predict the ground motions at various locations within the wing. The earthquake source was represented by an equivalent elastic source, and the motions were propagated over the region using a three-dimensional finite difference model. It was necessary to program the problem for the ILLIAC parallel processor computer, because of the number of computations required. This technique is being extended so that it can be used to predict motions from any earthquake or nuclear surface burst in the western United States.

In cooperation with AFOSR, a contractual study was made of the seismicity and seismic risk of the central United States, the northern Rocky Mountains, and Southern California in relation to the regional tectonics. Again with AFOSR, work has continued on the development of three-dimensional finite element models for the simulation of seismic effects on Air Force facilities. Improvements have been made to earlier computer codes to include damping and to minimize model boundary effects.

Missile Geophysics: In 1976 a silo motion study was conducted in a Minuteman test silo at Hill AFB, Utah. This study was designed to characterize the motion environment of the silo and identify those motions that introduce alignment and performance errors into the guidance system. The 1976 study was a follow-on to a 1974 study using the latest (Wing V-configured) Minuteman missile and suspension system without a reentry vehicle.

Again, the study was split into a seismic experiment and an azimuth alignment experiment. The seismic experiment was concerned principally with motions with periods of less than 1 minute, while the alignment experiment dealt with motion periods exceeding 1 hour. Measurements were made under ambient conditions as well as during selected maintenance activities and during two large, distant earthquakes.

The seismic experiment employed arrays of horizontal and vertical seismometers and tiltmeters located on the missile, in the silo, and in the ground surrounding the silo. Results from the seismic experiment indicate that for an event-free, midcontinental, rural, seismic environment, the missile roll can be modeled as a Rayleigh process which roll is caused primarily by air circulation in the launch tube from the air conditioning system. Due to larger airflow in the silos, missiles in other wings could be expected to exhibit roll motions up to 2 to 4 times that found during this experiment.

The alignment experiment employed an AFGL-developed Automated Azimuth Measuring System (AAMS) (described in the previous Report on Research) to measure the long period tilt and rotational motions of the silo, the missile skin, and the inertial guidance platform. Since temperature fluctuations induce tilts in both the silo and the AAMS instrumentation, temperature measurements were also made at selected points in the silo and near the AAMS instrumentation bench.

Analyses of the alignment experiment data were performed in three steps. The first step was to estimate the azimuth accuracy of the AAMS in the silo environment. A model of expected behavior of the entire AAMS was developed and verified using multiple regression analyses of the data for two intervals of several days duration. The second step was to determine the motion levels of the silo and missile from the AAMS tilt and azimuth measurements. The final step was to compare the measurements of long-period missile roll with the missile's own estimate of its azimuthal orientation, as indicated by the inertial performance data from the on-board computer.

Analyses of the data from the two test intervals showed good agreement with the theoretical model. Approximately 90 percent of the raw inertial azimuth variations of the AAMS were accounted for by the geokinetic model variables. In addition, the empirically determined coefficients agreed closely with the theoretical coefficients. Tilts on the silo collimator bench of over 5 arc sec were seen, and they had a high correlation with small changes in the ambient silo air temperature. Missile rotations of up to 5 arc sec of azimuth were measured by the AAMS during events as well as during a 2-day quiescent interval when the silo was completely sealed. Generally, missile rotations that were not directly related to specific events appeared to be related to small fluctuations in the silo ambient air temperature. Rotations of the missile, which is the azimuth reference for Minuteman III, were not evident in the guidance system's inertial performance data.

Automated Azimuth Measuring System (AAMS)

Recent Minuteman guidance improvement programs have made inertial performance data available from several operational missile wings. Inertial performance data from nearly all wings are expected to become available within the next year as the guidance improvement programs are completed. These data will provide an expanded data base for evaluating the effects of long-period geophysical motions on Minuteman guidance systems. Analyses of the spatial and temporal characteristics of limited segments of data have already begun. The results are being compared with other geophysical motion data in the respective areas and time periods to evaluate correlations between the motion data and guidance system anomalies. Studies will continue as more data become available.

As improved generations of inertial guidance systems are developed, the need for a portable, accurate azimuth standard that can evaluate geokinetic effects on a variety of azimuth references is apparent. To satisfy this need, a 2-year program is in progress to improve the azimuth accuracy, reliability, and automation of the Automated Azimuth Measuring System. The objective of this improvement program is to achieve a fully automated system with an accuracy of 1 arc sec (one standard deviation) over an integration period of 1 hour.

Unique to the AAMS are highly sensitive tiltmeters that are being installed in the inertial measuring units. By directly measuring tilts and tilt rates across the sensitive axes of the inertial gyrocompasses and removing the effects of high frequency motion-induced errors, a much-improved azimuth estimate should be possible. The approach differs from other inertial measurement systems in that it corrects for the effects of environmental motions instead of attempting to stabilize the measurement device in the motion environment.

SPECIAL STUDIES

The Division conducted numerous special studies for other Air Force agencies to evaluate the effects of ground and acoustically induced motions on systems and facilities.

In support of the Missile-X (MX) weapons system, a 2-month seismic study was conducted at the Defense Nuclear Agency's CASINO facility in Maryland. The study was designed to isolate radiation effects from seismic side effects generated during simulated electrical and mechanical component hardening tests of Third Generation Gyros. The study addressed itself exclusively to the nature of the seismic motions within the CASINO exposure cell excited by the test radiation shots. Seismic contributions for each individual test were delineated and their possible effect on the gyros considered.

In the spring and summer of 1978, the Division participated in the MISERS BLUFF II Explosion Program in western Arizona. Although the principal purpose of this program was the simulation of near-source effects due to close-surface nuclear explosions, AFGL's purpose was to determine ground transmission and local load characteristics for both near and far domains in support of the MX program. Seismic, tilt, and pressure sensor arrays were established near Parker, Arizona, some 35 km from a high explosive simulated nuclear source of 100 and 600 tons equivalent weight. In addition to the high explosive source, both train and truck sources were monitored for establishing a data base for future design criteria.

Also in 1978, in continued support of the SAMSO MX program, the ambient motion environment in the southwestern United States was surveyed in the Basin and Range geologic province. The MX, if deployed, will be sited in this region. Besides characterizing the observed and theoretical nature of the ambient motions in the area, ground intensity level determinations, formulated in terms of displacement and acceleration, were computed and compared with continental and worldwide averages. These considerations have import to hostile detection scenarios. Two follow-on studies in MX position location uncertainty will be conducted by the Division early in 1979 at Vandenberg AFB and the Nevada Engineering Test Bed.

The Division is also providing consulting services to the SAMSO-sponsored Space Transportation System Space Shuttle Program. A special study was conducted in 1977 to establish expected motion levels from future Space Transportation System launches. The results are being used for the engineering definition of vibration effects on existing and new facilities that will be subjected to extreme acoustic and ground vibration levels during a launch. Ground motions were first modeled using three-dimensional computer simulation algorithms. These algorithms generated the ground response of the local geologic environment due to impulse pad loads and acoustic loading of the models. The models were then field verified using missile launch data as well as that from high explosive sources within the Vandenberg AFB Space Transportation System launch complex.

Stand Alone Seismic Acquisition System, used for Special Studies.

Follow-on studies are programmed for 1979 to evaluate the vibro-acoustic effects on modified facility designs. These studies will provide data necessary to design for shock isolation of launch control and payload preparation facilities.

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VII OPTICAL PHYSICS DIVISION

The Optical Physics Division conducts research on the optical and infrared properties of the natural and man-made environment and radiation sources. This includes atmospheric transmission, infrared backgrounds, target signatures, and the development of new optical and spectroscopic techniques. Infrared backgrounds include the earth, atmosphere, aurora, airglow, horizon or earthlimb, celestial sky, zodiacal emission, and such man-made backgrounds as urban areas or nuclear weapon detonations. The research ranges from field measurements using aircraft, balloons, rockets and satellites to laboratory studies on molecular spectroscopy and interactions, electron excitation and high velocity collision phenomena, and theoretical studies and analyses.

The goal is to develop "tools" that can be used directly in the design and operation of Air Force and DoD systems. These tools include various data bases, models and computer codes such as the LOWTRAN atmospheric transmission and HITRAN laser transmission computer codes, the AFGL IR Star Atlas, and the LWIR Earth Limb Model.

The portion of the electromagnetic spectrum studied extends in wavelength from 2,000 Å in the ultraviolet to 1 cm where the far infrared blends into the microwave radio spectrum.

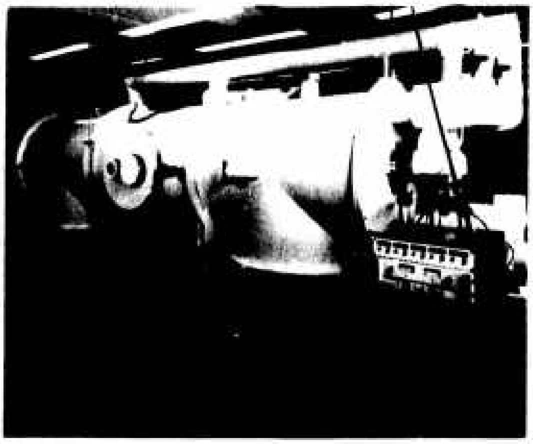
The research in the Division is divided into studies of: the visible and near visible properties of the atmosphere, where aerosol and molecular scattering is the predominant mechanism of attenuation; the infrared properties of the lower atmosphere where thermal equilibrium usually prevails; the optical and infrared properties of the upper atmosphere (including auroras and airglow) where individual molecular interactions must be considered; the infrared properties of exoatmospheric sources — stars, nebulae, zodiacal dust; measurements of the radiation from man-made sources such as missile or aircraft plumes or urban areas; and development of improved techniques for spectroscopic measurements.

A major area of investigation by the Division concerns atmospheric attenuation or transmission of radiation by the atmosphere, including laser beams. Atmospheric molecules absorb optical and infrared radiation selectively at discrete wavelengths. Extensive computer programs have been developed which make use of the vast collection of spectroscopic data for molecules (AFGL Atmospheric Absorption Line Parameters Compilation) and which permit the calculation of this transmission, particularly for laser beams (HITRAN). Detailed atmospheric absorption curves and tables for high resolution and laser transmission are available. The well known LOWTRAN atmospheric transmission computer code is used for determining the low resolution (approximately 20 wavenumbers) transmission of the atmosphere for any path through the atmosphere for a wide range of tactical weapon delivery problems under various meteorological conditions. Both the LOWTRAN and HITRAN codes have been designated as the standard atmospheric codes for the Department of Defense as part of the DoD transmission program and for the international research community as part of the Technical Coordination Program and the International Radiation Commission. The application of these codes to the emission and transmission of radiation from hot gases and plumes is under way.

The measurement and use of atmospheric transmission and emission also provide a method for remotely sensing atmospheric composition and meteorological conditions such as temperature, humidity, and ozone content. The transmission codes have been extensively applied to the design and improvement of remote atmospheric sensing instrumentation on the Air Force meteorological satellites.

Scattering by aerosols and molecules in the atmosphere also contributes both to attenuation and to reduction in the contrast of a target seen through the atmosphere. Extensive measurements in Europe as part of the NATO OPAQUE Program and from the Division's C-130 Flying Laboratory have been made to determine the geographic, seasonal and altitude variations, as well as the optical properties of these aerosols. The results of these measurements are applied to target acquisition and detection problems.

Similarly, infrared backgrounds against which a target must be located are a major concern of the Division efforts. Such emissions from the atmosphere or celestial sky represent interfering background noise superimposed on the optical/IR target signatures that a surveillance system may be trying to detect. The emission of the lower atmosphere can be calculated from computer programs similar to those discussed previously. However, the emission from the upper atmosphere (above about 70 km) requires a much more detailed knowledge of the interactions and collisions among the individual molecules, many of which will be in excited states with excess energy. The amount and wavelength of the radiation resulting from this non-equilibrium chemistry, and the effects of disturbances by protons and electrons as would occur during an aurora or a nuclear burst are also being studied. Therefore, a sizable laboratory and theoretical research program is conducted to study the physics and chemistry of the atmosphere, particularly those molecular interactions which lead to infrared emission, as well as an extensive measurement program. This has included both the use of the Division's NKC-135 optical/infrared



The exterior of the LABCEDE tank. The facility is approximately 15 feet long and 4 feet in diameter. The 32 inch diffusion pumps extend through the floor into the pump room below. The original electron beam was installed at the right hand end but has since been replaced by one mounted perpendicular to the axis, approximately at the center of the tank.

flying laboratory, and rockets, particularly in Alaska, where the infrared emission of the aurora is studied. Computer programs have been developed to predict and compute the IR emission of the earth limb and upper atmosphere, both for natural and disturbed conditions. Such background emission, particularly during disturbed conditions such as auroras, could seriously impair the operation of surveillance, detection, tracking, or terminal guidance systems.

A satellite or rocket-borne infrared system looking away from the atmosphere will still see the celestial sky as a background. Consequently, the Division is carrying out a rocket program to map the celestial sky as well as zodiacal emission in the infrared. Also, measurements of missile and aircraft plumes are being obtained from rockets and aircraft.

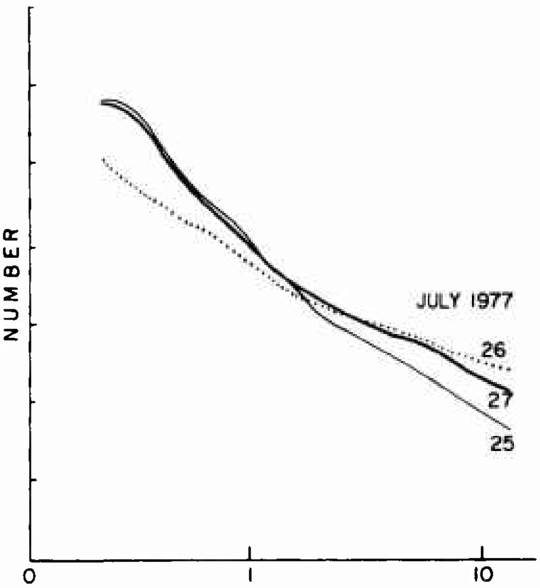
An inseparable part of these measurements and studies is the development and use of very sensitive advanced cryogenically cooled infrared sensors and spectrometers by the Division. Such a technique to which the Division has made significant contributions is multiplex spectroscopy, where all wavelengths entering the spectrometer-interferometer are analyzed simultaneously. This has included the development of a unique liquid-helium cooled high-resolution interferometer (HIRIS) which has been flown successfully on a rocket and is planned to be flown on future shuttle sorties. In addition, novel optical techniques are being explored to discriminate targets from these backgrounds.

ATMOSPHERIC TRANSMISSION

The atmospheric transmission of electromagnetic radiation in the ultraviolet, visible, infrared and even in the millimeter wave region is affected by molecular absorption and scattering and by extinction from particulates (dust, haze, fog, rain) in the atmosphere. The relative importance of these different attenuation processes depends on the wavelength of the radiation and on the atmospheric conditions.

In general, molecular absorption dominates the infrared to millimeter region of the spectrum, whereas aerosol extinction dominates the visible part of the spectrum. This domination is not complete, however, and a full understanding of atmospheric propagation requires thaz we deal with the appropriate molecular and aerosol effects at all wavelengths. Molecular absorption is highly wavelength dependent, whereas aerosol extinction varies much more slowly with wavelength. In the infrared, this rapid wavelength dependence tends to determine the "windows" within which atmospheric propagation is possible, whereas the transparency within these windows tends to be determined by more slowly varying molecular "continuum" and aerosol effects. As a result, aerosol and cloud attenuation can be the critical factor not only for visible wavelengths, but also for infrared radiation in the window regions.

Aerosol and cloud drop attenuation can affect radiation propagation in several ways. Particulate scattering and absorption along with molecular attenuation reduces the intensity of a beam of radiation as it travels along an atmospheric path and thereby becomes a factor in determining beam transmittance (e.g., in laser beam propagation). For many applications one is not only concerned with the extinction loss in a beam of radiation, but also with the intensity and angular distribution of the radiation scattered out of the direction of propagation of the direct (incident) beam. One of the most important effects of this scattered radiation is the reduction of contrast in imaging systems at visual and near IR wavelengths. The scattered light from the sun forms the background sky radiance against which objects may have to be viewed and detected.



Changes in particle size distributions as air masses change. Winds from the southwest brought air containing large numbers of small particles (les s than 1μm) on July 25, 1977 (light curve). On July 26, the winds shifted to the northwest, and the number of small particles dropped by a factor of 10 (dotted curve). On July 27, the wind returned to the southwest, and the numer of particles less than 1 μm rose again to the concentrations noted on July 25 (heavy curve).

With some exceptions, which are discussed below, the attenuation processes by atmospheric molecules are sufficiently well understood to make accurate predictions of the attenuation effects when the basic atmospheric properties such as molecular concentrations, air temperature, and pressure are known.

It is much more difficult to predict accurately the optical properties of particulate matter in the atmosphere, especially those of haze and dust particles. Their optical effect is not only a function of particle concentration, but also of particle size, shape, chemical composition and physical structure. All these properties are highly variable with weather conditions and location and they are very difficult to measure. Because of the extreme variability of these properties, it is also very difficult to develop models for the optical/IR properties of aerosol particles or droplet clouds.

The final goal of this research in the Optical Physics Division has been the development of computer codes which allow an efficient and accurate calculation of these various atmospheric propagation properties.

Measurements: The Optical Physics Division has directed a significant portion of its efforts toward experimental studies of the aerosol optical/IR properties and the development of realistic and representative models for these properties. One of these experimental efforts during the past two years was performed as part of a larger measurement program involving several NATO countries in Europe. Under this program, called Project OPAQUE (OPtical Atmospheric QUantities in Europe), routine measurements of visible and IR transmittance, path radiance, illuminance, and meteorological parameters including aerosol properties are being made at selected sites.

The Air Force Geophysics Laboratory, in cooperation with the Federal Republic of Germany, has been conducting these measurements on a regular basis since the winter of 1976-1977 in Northern Germany. This measurement program has already resulted in a number of important conclusions on the physics of aerosols and on the effect of aerosols on the propagation of radiation. A few examples are presented below.

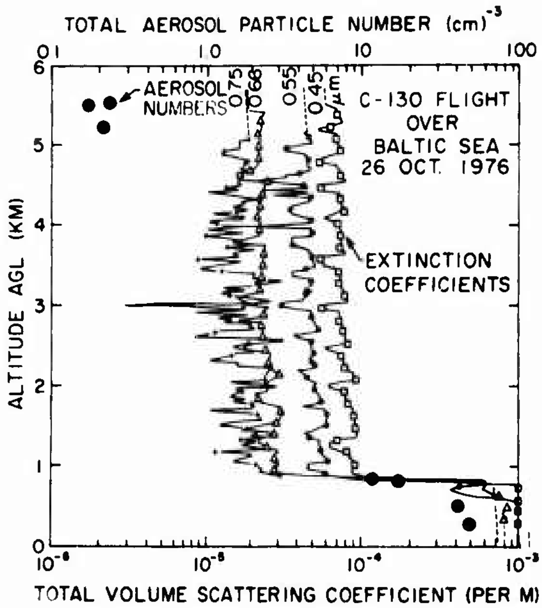
Aerosol Data and Models: Air mass optical and aerosol properties are modified by continental and anthropogenic influences. In particular, the maritime polar air masses reaching Northern Germany from the North Atlantic are modified by their passage over England, France and/or the industrialized low countries. The degree of modification is directly related to the trajectory followed by the air mass and the residence times along that trajectory. Aerosol data taken on three consecutive days, 25 to 27 July 1977, during a "surge" of maritime polar air, illustrate the effects of continental modification.

The synoptic regime was relatively distinct. During most of the day of 25 July, the measurement site was in front of a northeast-southwest oriented cold front in an area of light southwesterly winds. On 26 July, after the frontal passage and a strengthening of the low pressure center over Norway, a surge of cool maritime polar air moved rapidly from the open ocean, over England and into Northern Germany. As this flow weakened during the night of the 26th, a new frontal system was passing over France. As a consequence, on the 27th, the winds at the OPAQUE site swung back to the southwest After the frontal passage, the northwesterly flow was associated with better visibilities and rain showers. The associated aerosol samples indicate that with this change, the number of particles smaller than $1\mu m$ decreased by a factor of 10 while the number of 10 μm particles increased by a factor of 10. The aerosol data from the 27th then indicate that with the return of the southwesterly flow, the number of small particles returned to the numbers observed two days earlier in the southwesterly flow, and that the number of large particles decreased slightly from those in the northwesterly flow.

The suggestion in these data is that the surge of air from the northwest was much cleaner overall than the air present on 25 July, but that the maritime air is characterized by large numbers of larger particles. The data from the 27th are also probably from maritime polar air, but with a longer trajectory over industrialized areas. The result of this trajectory is the introduction of large numbers of small particles while at the same time larger particles are being removed by various physical processes. These results were expected and confirm some of the many concepts about air mass modification. It remains for us to broaden the knowledge base with appropriate correlation studies and to develop a useful statistical base for determining air mass characteristics after a given migration or stagnation.

Another important question is: How does the composition, especially the size distribution of aerosols change with altitude? Vertical aerosol size distribution and extinction coefficient variations were measured on a number of aircraft survey flights in Europe in connection with the surface measurement program. Very often one finds in industrial urban environments a very distinct low level haze layer near the surface. The aircraft measurements show that the size distribution and also the composition of aerosols can vary considerably with altitude, depending on the vertical structure of the atmosphere.

Within the OPAQUE measurement program, aerosol particles have also been collected with high volume air samplers, and the aerosol substance subsequently analyzed for its refractive index and absorption properties. From these studies it was found that the composition of aerosols varies not only with time and location, but that it is not uniform throughout the whole size range of particulates. The refractive index components (real and imaginary part) show some distinct spectral variations



Comparative vertical profiles of measured scattering coefficients and aerosol number densities, as measured on a C-130 flight over the Baltic Sea on October 26, 1976.

which can be associated with different chemical components.

Based on the OPAQUE data and other experimental data from various researchers, aerosol models have been developed and their optical and infrared extinction and scattering properties have been derived.

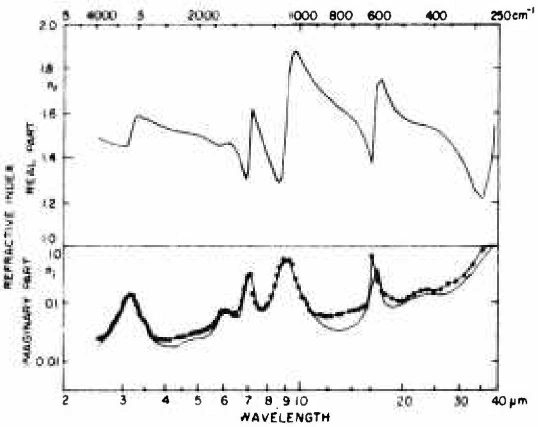
Since measurements and theoretical studies by several scientists have shown that the aerosol size distribution and their refractive index change significantly at high relative humidities, these humidity dependent changes and resulting optical properties were also incorporated into the optical/IR aerosol models. At relative humidities above approximately 70 percent, and especially in the 90 percent region, aerosol particles begin to adsorb water molecules and grow. The rate of growth is not the same for all particles. In general, it is higher, the more hygroscopic and the larger the particles. As a consequence, the optical properties of aerosols change and the wavelength dependence of the extinction coefficient decreases.

This change in optical properties of aerosols with relative humidity depends very strongly on the chemical composition of the aerosols. Hygroscopic particles in maritime aerosols (sea salt) grow much more rapidly and at lower values of relative humidity than non-hygroscopic dry dust particles in a rural continental type aerosol.

Such models of the optical/IR properties of aerosols have little reliability unless they can be verified against experimental data. Measured optical/IR propagation properties from the OPAQUE program in Germany offer an extensive data base for such tests. They show that, in general, the IR extinction and scattering properties of the model describe the measured parameters very well, using visibility and relative humidity as input parameters. The major uncertainty in such model calculations is the decision on which type of aerosol model best represents the aerosol composition at the time of the measurements of the optical/IR propagation properties.

Atmospheric Transmission Modeling: The transmission modeling program includes the effects of extinction by both molecular and particulate (aerosol) constituents of the atmosphere. Models for predicting the transmission, thermal emission, and scattered radiation properties of the atmosphere have been developed for both high and low spectral resolution applications. Two basically different transmission models have been developed. The underlying basis for their development is the spectral resolution of the calculated transmission which is primarily governed by the widths and spacing of atmospheric molecular absorption lines.

The LOWTRAN 4 model differs from previous LOWTRAN models in its ability to compute thermal emission as well as atmospheric transmission. It maintains all the capabilities included in its predecessor LOWTRAN models: contributions by absorption lines, continuum absorption by water vapor and other molecular species, and the absorption and scattering by atmospheric aerosols. Work is proceeding to obtain new laboratory measurements of the water vapor continuum absorption, particularly in the 3 to 5 μm spectral region. A revised continuum model is planned for a forthcoming LOWTRAN model. Current LOWTRAN modeling efforts are centered on the validation of the LOWTRAN code by comparison of the models with measurements made in the atmosphere. The emphasis in these validation efforts is on aerosols.



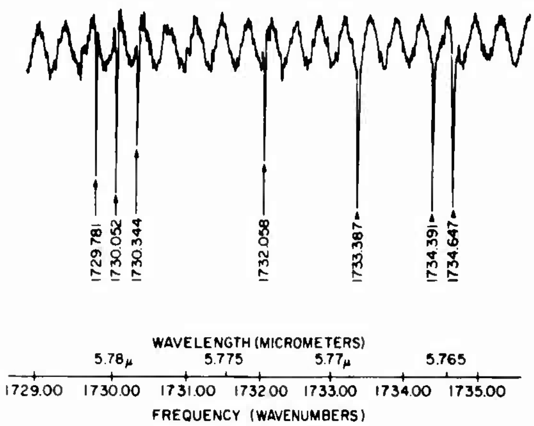
Absorption indexes of aerosols taken at the OPAQUE site in Northern Germany for particles larger and smaller than 1 μm.

The second atmospheric transmittance model, HITRAN, uses the summation of the individual molecular absorption line profiles of the various atmospheric gases to determine the monochromatic transmittance at each wavelength. This method is known as a "line-by-line calculation" and can be used to determine the transmittance of the atmosphere at any given spectral resolution by averaging over the required spectral interval. This is the only approach capable of computing very high resolution spectra for the transmittance of laser beams through the atmosphere. This approach may also be used to predict atmospheric propagation characteristics for spectral resolution up to the 20 wavenumber capability of LOWTRAN. A new HITRAN routine known as *FASCODE - (Fast Atmospheric Signature Code)* has been developed recently. It computes high resolution spectra at a substantial saving of computer time. It has been published as *FASCODE - Fast Atmospheric Signature Code (Spectral Transmittance and Radiance)*, AFGL-TR-78-0081. The FASCODE algorithm is based on an optimal sampling of simple mathematical functions, the sum of which is equal to a particular absorption line shape.

A frequently asked question is: What laser frequencies are attenuated the least by the atmosphere? This question has been answered for carbon monoxide, hydrogen fluoride, deuterium fluoride and carbon dioxide laser systems in a summary report on laser transmittance (AFGL-TR-78-0029) which describes the new "LASER" code now available for distribution. In addition to addressing the problem of laser propagation of these specific laser systems, the summary report provides synthetic spectra for a large portion of the infrared, allowing a quick estimate of atmospheric attenuation for laser propagation. The compilation of atmospheric absorption lines used as a basis for much of our work is described in the *AFCRL Atmospheric Absorption Line Parameters Compilation* (AFCRL-73-0096). Since the publication of this report in early 1973, we have made available over 200 copies of these data on magnetic tape. Additional short articles have been published to inform the scientific community of significant modifications and additions to the data base. Detailed information on over 140,000 spectral lines in the spectral region from 0.68 μm to the microwave region are contained on this tape. Atmospheric species included in the compilation are: H_2O, CO_2, O_3, N_2O, CO, CH_4 and O_2.

A special version of the HITRAN code has been developed to calculate atmospheric transmission (attenuation) in the microwave, millimeter, and submillimeter wave regions. The frequency range considered is

1 to 1000 GHz or 0.03 to 33 wavenumbers. The clear atmosphere transmission spectra is calculated by a computer-efficient extension of the HITRAN code. The hydrometeor transmission of fog, clouds and rain (as calculated by Mie scattering) is appended to this HITRAN code. This new code calculates atmospheric transmission for "all weather" transmission through an arbitrary atmospheric path.



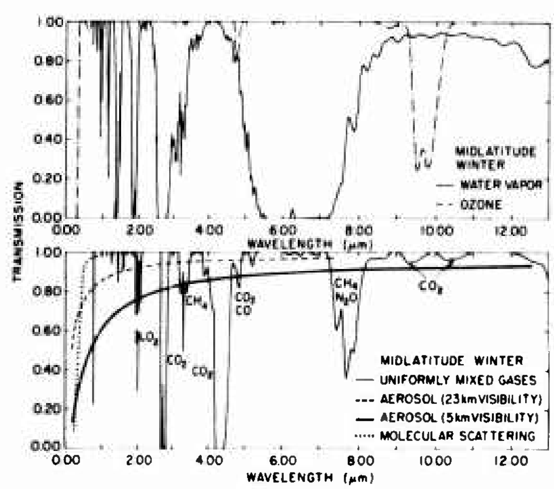
Comparisons of experimentally measured absorption lines of water with the AFGL line compilation. The low amplitude sinusoidal variation at the top of the measured spectrum is a channel spectrum caused by multiple reflections within the instrument. The wavenumbers predicted by theory and the differences between theoretical and experimental values are noted for each line.

Current efforts involve improving the HITRAN data base, both by correcting existing data and adding new material. New material to be added includes weak absorption features of the major atmospheric absorbing gases. Absorption parameters for trace atmospheric and pollutant gases comprise a separate tape which is also available to the scientific community. The gases included on this trace gas tape are NO, NO_2, NH_3, and SO_2. Work is also under way on OH, HNO_3, HCl and HF.

Research on molecular spectroscopy is being conducted to provide the capability of calculating molecular spectroscopic parameters related to some of these atmospheric gases. The parameters being studied include transition frequencies, intensities, line widths, line shapes, and radiative lifetimes. Molecular constants are determined from available spectroscopic data and used to predict spectral information at desired conditions of temperature, pressure, and abundance. Computer codes have been developed to calculate molecular constants that are difficult to measure, including those for high vibrational states populated at high temperatures and for isotopic species that are significant in weak absorption regions of the atmospheric spectrum.

Applications: During the past several years, a great deal of the modeling effort has been in direct response to specific application requirements. The development of the LOWTRAN code was spurred by such requirements. Both HITRAN and LOWTRAN have been applied to a wide variety of laser and broadband tactical system design and application problems.

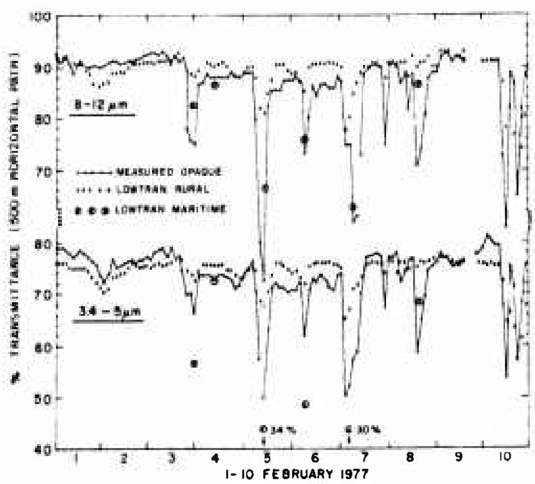
Another application of the transmittance modeling activity is the problem of the satellite remote sensing of meteorological variables. The Line Parameters Compilation has been used as a data base for such calcu-



Atmospheric transmission along a vertical path from sea level to space, computed with the LOWTRAN model.

lations to determine the spectral channels most suitable for use in satellite sensor design. In addition, transmittance calculations performed with these models are being used in the development of software packages for the reduction of satellite-measured radiances in terms of the three dimensional structure of temperature and moisture.

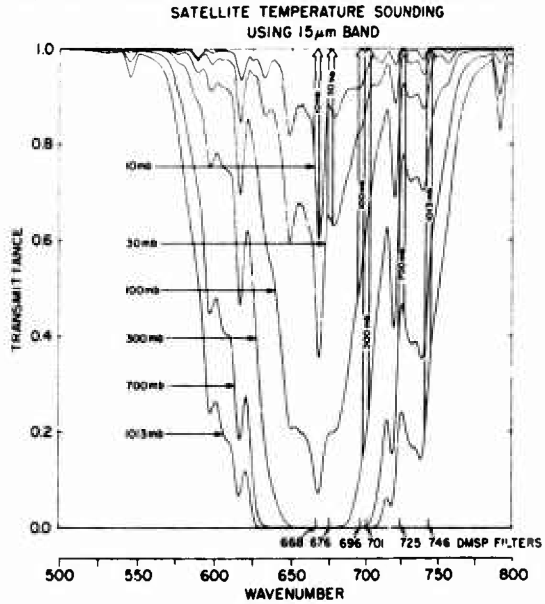
The Line Parameters Compilation has also been applied to the understanding of the sugnature of a hot gas (for example, the exhaust plume of an aircraft) as viewed through a colder intervening atmosphere. In conjunction with aircraft-borne measurement programs, these calculations allow us to investigate the altitude and range dependence of exhaust plume emission signatures.



Comparison of LOWTRAN calculation of transmittance along a path in Northern Germany with OPAQUE program measurements.

Remote Sounding: The first meteorological satellites were designed to transmit cloud pictures. It was soon realized that the atmospheric emission in the thermal infrared region of the spectrum was related to the temperature of the atmosphere, so that remote passive temperature sensing was possible. This possibility follows from the relation between the atmospheric emission in the thermal infrared region of the spectrum and the vertical atmospheric temperature field. Vertical temperature inferencing became operational in 1970 with the orbiting of the Vertical Temperature Profile Radiometer (VTPR) sounder aboard a NASA-NOAA meteorological satellite. Similar data observed by the Defense Meteorological Satellite Program (DMSP) became generally available in 1974. Later versions of these vertical sounding systems also contain spectral channels intended to sound the vertical distribution of water vapor, a parameter of substantial interest to the Air Force.

Work in the Division has been concentrated in two areas. First, the transmittance modeling described above has been applied to the development of new design concepts and data analysis techniques for the remote sounding of the vertical distributions of temperature and water vapor in the infrared and microwave regions of the spectrum. Modifications to existing infrared sensors have been proposed and constructed and these modified sensors will be

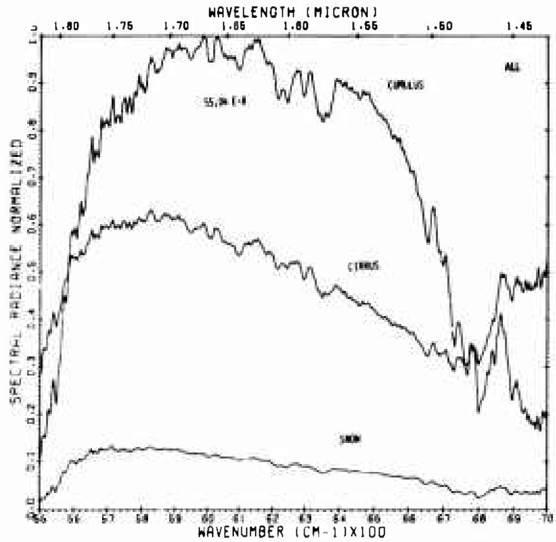


Satellite temperature sounding using the 15μm band. Arrows indicate the approximate atmospheric levels from which the radiation at the frequencies of the DMSP channels is emitted to space.

flown on future Defense Meteorological Satellites. A study of water vapor and 15-μm carbon dioxide transmittances is under way to aid in the understanding and interpretation of discrepancies found in comparison of satellite measured and computed atmospheric radiance distributions. Second, the ultimate utilization of the satellite measured radiances in the thermal infrared requires an inversion procedure, a mathematical device whereby either the vertical distribution of temperature (or water vapor) or the vertical distribution of the sources and sinks of radiation in the atmosphere are derived from a spectral scan of the upwelling radiance. This information is then fed into dynamical models of atmospheric motion as a key element of weather forecasting on various scales.

Using such a spectral scan to determine the temperature (or moisture) at each level in the atmosphere has proved to be very difficult. All levels of the atmosphere contribute at each particular frequency, so that the radiance sensed by the satellite is a mixture of thermal information from all levels. Probing different frequencies merely weights radiation according to height, depending on the transmittance of the atmosphere.

Mathematically, the radiation is expressible as an integral transform of the temperature-related Planck intensity summed over the atmosphere. Typically, the radiances are observed over six to eight different frequency channels. The vertical temperature distribution is then recoverable as an inverse transform of the radiance profile; hence, the name inversion given to this particular inference problem. The heart of the problem is that the vertical temperature distribution is deduced from intensity differences between neighboring frequency channels, a second order effect. First, the finite number of channels of observation means that many solutions for the temperature profiles are possible. Second, most inversion methods use some a priori algorithm in an attempt to smooth out the inevit



Average spectral radiance values of snow and clouds as measured from the AFGL KC-135 aircraft.

able noise in the data and thus run the risk of discarding useful information. Techniques are being developed which will recognize noise in the radiation measurement data and eliminate it from the data base which is then used to infer temperature profiles.

Snow Cloud Discrimination: Near infrared spectral measurements were taken of snow, cirrus, and cumulus backgrounds by the Air Force Geophysics Laboratory's KC-135 aircraft. Based on an analysis of 124 aircraft measured spectra, the spectral reflectance characteristics of snow, cirrus and cumulus between 5500 and 7000 wavenumbers were determined. Certain snow cloud discrimination design parameters were identified, i.e., slope of the spectral radiance, absolute spectral and/or total radiance and the location and value of the maximum spectral radiance for each background. It was suggested that an optimum snow cloud discrimination should be based on the measurement of the slope of the spectral radiance in this near infrared region.

INFRARED BACKGROUNDS

It is impossible for a sensor to observe or look in any direction without encountering the emission or radiation from some "background" — whether it is the celestial sky, the earth and clouds, the horizon or earth limb, the aurora or airglow, the atmosphere itself or even manmade backgrounds such as nuclear explosions or urban areas. Much of the research of the Division is devoted to obtaining direct measurements of these backgrounds, and developing data bases, models and codes to describe these backgrounds and the phenomenology related to them.

In particular, the optical/infrared properties of the upper atmosphere, both under normal conditions and when it is disturbed by auroras or nuclear backgrounds, is a major scientific area. At the altitudes considered, thermal equilibrium usually does not exist, and it is necessary to consider the collisions or interactions of individual pairs or triads of molecules, one or more of which may be an excited state (that is, with excess internal energy). Extensive laboratory and theoretical studies, as well as rocket and aircraft measurements of upper atmospheric optical/infrared phenomena, are carried out. The results of these laboratory studies and aircraft measurements also apply to missile or jet engine plume infrared radiation. The goal of the research is to generate both directly measured data and models and computer codes that permit the prediction of the optical/infrared emission of the upper atmosphere, particularly under disturbed conditions. Such data and codes are particularly applicable to surveillance and detection systems operating in space or near space.

Aircraft Measurement Program: AFGL uses a modified NKC-135 aircraft as an Infrared Flying Laboratory. This aircraft is

The AFGL Infrared Flying Laboratory. The viewing ports, except for those looking straight up or straight down, are visible in this picture.

configured with 55 viewing windows and ports behind which various radiometers, interferometers, spectrometers, and spatial mappers can be operated to collect basic infrared data. The range of this aircraft allows worldwide deployment and permits the infrared research scientists to study the environment well above obscuring clouds and atmospheric constituents. This NKC-135 has been serving as a reliable platform to study geographic and seasonal impacts upon infrared processes in the aurora and atmosphere. These studies are coordinated with balloon and rocket-borne measurements with the data used to test specific theoretical and laboratory-based modeling.

A variety of unique instrumentation is carried on board the Infrared Flying Laboratory. Three Michelson interferometers are utilized, two of which are mounted at side-looking windows and the third at a down-looking window in the converted refueling "boomer's compartment." These instruments have been designed and built by a member of the scientific air crew and the data obtained are widely acclaimed by the DoD infrared community. Two thermal scanners are operated simultaneously with the interferometers, providing infrared imagery that serves a dual purpose: 1) providing independent sensor data of phenomena being measured; and 2) providing visual support enabling better interpretation of interferometric spectral data. One scanner is mounted at a side window and the second, with a cryogenically cooled detector, is mounted at a downward window adjacent to the down-looking interferometer. Temporal data are obtained from a four channel radiometer mounted at a side window. An array of 16 mm tracking cameras and a television camera provide visual documentation of subjects being observed.

The data obtained with these various instruments are recorded on analog tape recorders and the tapes returned to the laboratory for reduction. From the interferometers come digital plots of infrared spectra in units of absolute spectral radiant intensity for targets, or absolute spectral radiance for backgrounds and extended sources. The infrared scanners provide computer enhanced imagery that gives differential radiance with respect to the mean radiance of the scene. The radiometer provides calibrated source radiances that can be compared with integrated spectral data; if the source varies in intensity, curves may be obtained from computer plots showing time history of the measured radiation.

Interferometric and spatial data products are generated in the laboratory by a powerful array of minicomputer hardware. The interferometric data are transformed from raw analog interferograms into digitized spectra with a minicomputer and Fourier analyzer. The spatial imagery data are processed and converted to television images that are calibrated relative to an arbitrary background level by the minicomputer. The images are displayed on a standard TV monitor in a 16-step grey scale format by a video display unit.

The airborne infrared measurements program is collecting large amounts of data on a variety of targets and backgrounds. Spectral and spatial background data have been collected on desert, urban, rural, cultivated, mountain, snow, and water backgrounds. Sky background data consists of several cloud types viewed from above and below at several altitudes and various solar azimuth and elevation angles. In addition, continuous urban and rural data have been obtained for a period of approximately five hours, beginning before sunset and ending after sunset for three different seasons of the year.

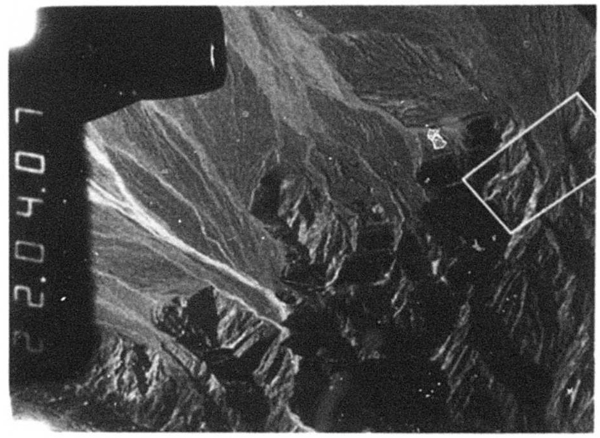
The aircraft missions have obtained data necessary to Air Force and DoD research and development programs. A typical example of field data is taken from a mission of December 1975 over the desert of Death Valley, California. Circling at 25,000 ft above the desert floor, the interferometer and the spatial mapper recorded the infrared signature during the entire 360 degree orbit. Such measurements show that spectral radiance reaches maximum intensity when the viewing angle is away from the sun and minimum when the viewing angle is into the sun. This occurs because the percentage of shaded surface is minimized and, therefore, reflection of solar radiation is maximized when viewing away from the sun and vice versa. Comparison of calculated surface temperature based upon spectral analysis has been close to weather data surface readings in view of the uncertainties of thermal coupling of the surface with the atmosphere, intermittent shading by clouds, and so forth. This has helped establish confidence in the reliability of the data.

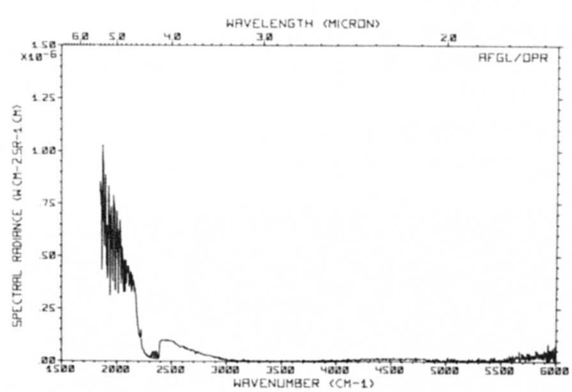
Design, construction, and testing continues with follow-on generations of instrumentation. An interferometer has been equipped with an automatic mirror alignment system that promises to contribute even more stability to the data. A new interferometer is under construction which incorporates a unique linear drive system for the primary mirror and an improved servo-controlled alignment system. This new instrument will be capable of producing data with 0.1 wavenumber resolution. A new FLIR spatial mapper system has recently been installed in the NKC-135 and will begin testing in January

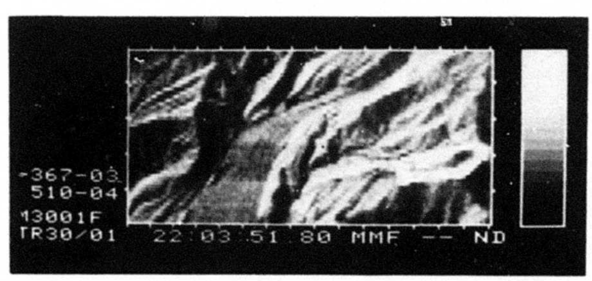
1979. It will provide thermal imagery with four times the resolution of the infrared scanners currently in use.

Balloon-Borne Measurements: The purpose of the Balloon Altitude Mosaic Measurements (BAMM) Program is to obtain infrared background data related to the stability of the earth/atmosphere as a radiation source. The measurements are designed to measure the scintillation produced by the atmosphere, characterize the IR emission properties of clouds, obtain earth emission correlation lengths and observe the noise spectrum of the radiation from the earth/atmosphere system. To measure these parameters, it is necessary to observe them from a stabilized platform from which the optical path always traverses the same portions of the atmosphere. Consequently, a high-altitude, slow-moving balloon carrying a trainable platform was selected as the vehicle to carry the IR instruments. The platform performs mechanical maneuvers to compensate or eliminate balloon motions of rotation, pendulation, and drift. A gyrosensor-servo system automatically controls, through a microprocessor, a three-axis gimbal to maintain continuously pointing stability to better than one arc-sec per sec. With this very accurate inertial stabilization, a point on the earth's surface can be observed in a staring mode such that the observed image does not move appreciably in over three minutes. Measured changes in the intensity of radiation recorded in the stare mode may be directly related to atmospherics affecting the radiation; for example, twinkling. In addition to maintaining a constant line-of-sight, the platform is capable of scanning 360 degrees in azimuth and horizon-to-horizon in elevation to obtain spatial frequency measurements and thus isolate the scintillation from changes produced by ground structure.

A radiometer and Michelson interferometer located on the balloon platform measure the infrared. Both instruments have 4 x 4 mosaic detector arrays in the focal plane which image 0.8 x 0.8 km of the earth





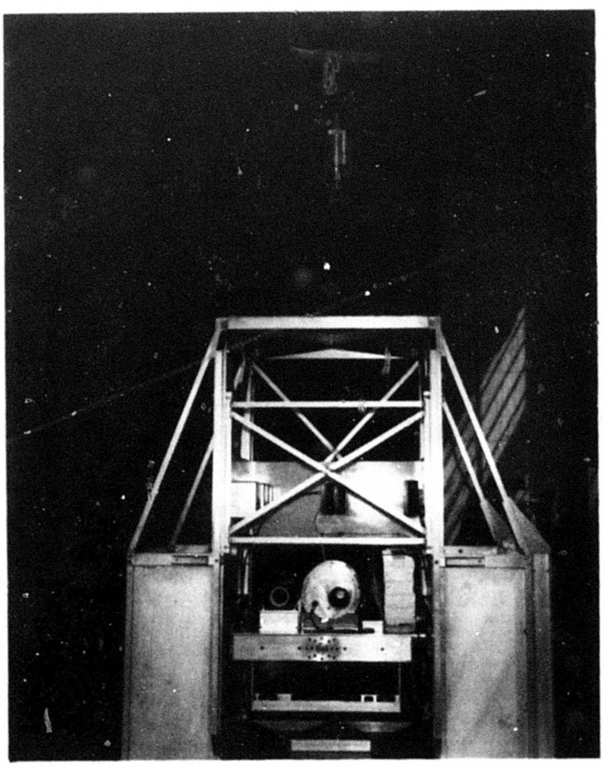


A typical desert background measurement. The visual photo, spectrum, and thermal image were taken at the same time from 25,000 feet altitude. The sun was in the southwest (216 degrees) and 22 degrees above the horizon. The aircraft banked 45 degrees and was flying northwest (286 degrees) when the picture was taken.

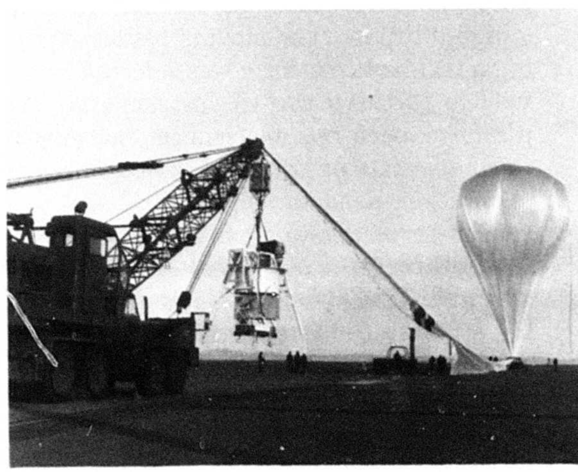
surface on each detector in the array. The radiometer contains fixed band filters which may be changed on ground command while the interferometer covers the 2.5 to 5.5 μm spectral range with ten wavenumber resolution. Spectral measurements are recorded in the staring mode so as to obtain the background temporal changes within each spectral element over the frequency range of DC to 10 Hertz.

A TV camera mounted on the pointing platform is used for visual real-time background scene acquisition and system navigation. The TV package is a standard camera modified optically to provide a ground resolution of 1,000 feet at the balloon altitude of 100,000 feet. With a motorized zoom feature, the TV scene can be changed to increase the spatial resolution by a factor of 10 to give 100 feet ground resolution. All instruments are boresighted to view identical scenes on the earth's surface in order to analyze and compare the infrared intensity of different background scenes, such as clouds, mountains, lakes, or desert, with the visible scene.

The first measurements using the specialized payload were made in September 1978 from Holloman AFB, New Mexico, from a 2.7 million cubic foot balloon. Infrared data and TV video pictures were collected on a variety of backgrounds typical of the desert surroundings. Preliminary analysis of the data shows that the infrared power decreases with the square of the spatial frequency. Measurements are planned for the spring and fall of 1979 in the southeastern and southwestern parts of the United States.



The gondola for the Balloon Altitude Mosaic Measurements (BAMM) Program. The sensor and television camera have been rotated so that they are looking sideways.



The BAMM payload and balloon ready for launch.

Background Measurements in Space: The Air Force needs to detect infrared emitting targets in space at the greatest possible range. Because these targets are always viewed against background radiance, knowledge of this radiation is necessary to permit discrimination of the target from the background. These backgrounds include the celestial sky, zodiacal emission and radiation from the earth limb, aurora and upper atmosphere.

The scope of the problem is determined by the requirements of the space surveillance program. The first requirement is a specification of the celestial background. We must be concerned not only with stars but, in addition, take into account the effects of zodiacal radiation — that is, thermal emission from particles distributed about the ecliptic plane caused by the absorption of solar radiation. The additional requirement to observe ow-altitude satellites means that we must determine the lower limit set by the earth's upper atmospheric limb radiance.

The Division has conducted a series of experiments to obtain infrared survey data on the celestial background with state-of-the-art cryogenically cooled sensors flown on rocket probes. The thrust of the program has been threefold: to obtain the most complete sky coverage possible with as high a sensitivity as comparable with the need to cover a large area on each flight; to generate from these data a background map; and to apply these data to the model to extend statistically the empirical data base to faint irradiance levels.

To date, about 79 percent of the sky has been surveyed at an effective wavelength of 4.2 μm, 90 percent at 11 μm, 87 percent at 20 μm and 36 percent at 27 μm. The data have been published in *The AFGL Four Color Infrared Sky Survey: Catalog of Observations at 4.2, 11.0, 19.8 and 27.4 μm* (AFGL-TR-76-0208). A subsequent catalog (AFGL-TR-77-0160) extends the data to sources observed with low confidence. Many of these latter sources have been confirmed by ground-based observations.

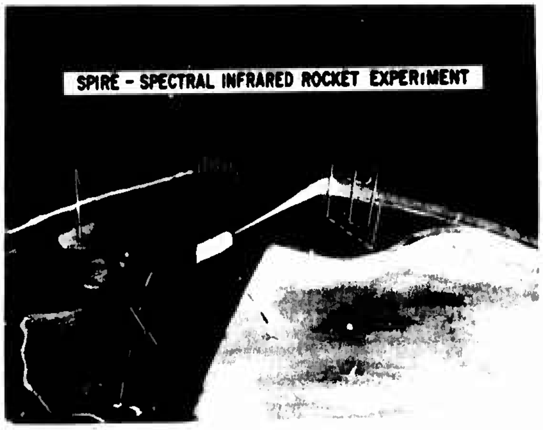
Present plans are to develop instrumentation to be flown on an ARIES compatible payload which gimbals the cryogenic sensor. Each flight will survey approximately 35 percent of the sky at effective wavelengths of 11, 20 and 28 μm. The optics will permit scanning to −55 degrees in declination from White Sands Missile Range with no degradation in sensitivity, permitting coverage of the important area south of the galactic center.

Preliminary data for the earth limb and zodiacal radiances were obtained August 3, 1976, from a rocket probe launched at White Sands Missile Range, New Mexico. The experiment took advantage of the excellent out-of-field-of-view rejection characteristics of the sensor. The combined experiment obtained data of the earth's atmosphere as well as zodiacal data, particularly at angles close to the sun. The zodiacal light represents the limiting background for observations made in deep space. The present program envisions experimental flights to provide the basis for a complete model of the zodiacal light. The cryogenic sensors for carrying out these measurements are being designed and constructed at AFGL.

Parallel efforts to develop computer codes which model the infrared radiance from the upper atmosphere have been under way for the past five years. The model incorporates photochemical and thermal emission mechanisms for the major infrared active molecular species. Radiance profiles can be generated in the 5 to 25 μm region up to 500 km altitude. A new model (AFGL-TR-77-0271) which incorporates revisions made since 1974 is now available. A rocket probe program to measure the vertical distribution of atmospheric radiation is currently under way. Launches are scheduled for sunrise, noon and sunset to obtain the diurnal variation of the atmospheric background. The data, which will cover the 3-22 μm region, are intended to update the current infrared limb radiance model.

CIRRIS: An experiment called CIRRIS (Cryogenic Infrared Radiance Instrumentation for Shuttle) is being conducted by AFGL with flights on space shuttle planned for 1982 and 1984. This experiment will obtain high resolution spectral and spatial data of the infrared emissions from aurora, airglow and earth limb backgrounds as well as obtain much needed data on contamination of the space shuttle environment. The CIRRIS I sensor to be flown in 1982 will be a combined interferometer-radiometer containing a single detector element. The CIRRIS II sensor will have a 14 element detector array in both the interferometer and radiometer to provide simultaneous data on spectral radiance and spatial distribution of emissions over the broad spectral range from 2.7 to 25 μm. The sensor design is based on the liquid helium cooled interferometer-spectrometer technology developed at AFGL. The experiment is planned for 7 to 14 day shuttle sortie flights with low altitude, high inclination orbits.

SPIRE: A rocket experiment called SPIRE (Spectral Infrared Rocket Experiment) was conducted by AFGL under the sponsorship of the Defense Nuclear Agency to investigate earth limb infrared emissions. The 2100 lb. payload was launched on a Talos Caster rocket on September 28, 1977, near dawn from the University of Alaska's Poker Flat Research Range and achieved an apogee of approximately 285 km. Primary sensors on the payload included two circular variable filter (CVF) infrared spectrometers covering the wavelength region from 1.40 to 16.5 μm and a dual channel photometer to measure visible emissions in narrow bands centered at 4977 Å and 6972 Å. The sensors were coaligned and equipped with high off-axis rejection telescopes with nominal fields of view of 1/4 degree full angle which provided an optical footprint size of about 8 km at the tangent height point. The payload attitude during ballistic flight was controlled by an inertial system programmed to accomplish vertical spatial scanning through the day, terminator and night portions of the earth limb region. Excellent data were obtained from the primary sensors during rocket ascent and descent resulting in over 1500 infrared spectral scans from the spectrometers and 400 seconds of continuous photometer data. The emission data encompasses 12 vertical spatial scans from tangent heights of 250 km down to full viewing of the hard earth, as well as one spatial azimuth scan from full night, through the terminator, to full sunlight conditions.

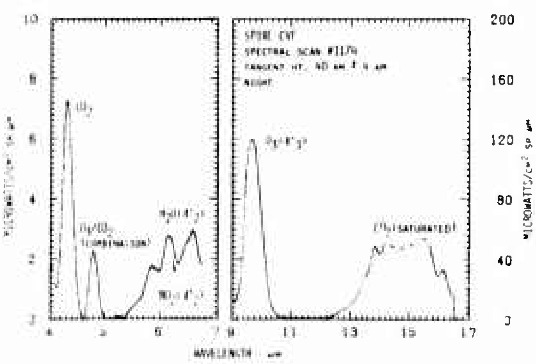


Artist's concept of the SPectral Infrared Rocket Experiment (SPIRE) mission showing the relationship of 12 spatial scans to the earth limb at the dawn terminator.

High quality, first-of-a-kind spectra of high and low altitude molecular emission were obtained throughout the 1.4 to 16 μm spectral range. Non-equilibrium emissions above 60 km include the OH fundamental and overtone, NO at 5.4 μm, O_3 at 9.6 μm and CO_2 at 4.3 and 15 μm. Comparisons of these measurements with the AFGL developed high altitude radiance model yield generally excellent agreement, with several notable discrepancies in the radiance profiles. These include evidence of a second hydroxyl layer at 65 km and the apparent interruption in the steady drop of CO_2 15 μm radiance with altitude in the 100- to 110-km region. This latter effect is similar to an "anomalous" CO_2 profile obtained earlier by a vertical viewing spectrometer during the ICECAP program.

SPIRE's limb viewing aspect combined with the high off-axis rejection capabilities of its sensors made it possible to probe down to altitudes within 15 km of the hard earth. This allowed measurements through the transition region to thermodynamic equilibrium (70 to 40 km) where models are inaccurate and *in situ* sounding rocket and balloon measurements do not overlap.

Results show a smooth transition for stratospheric water at 6.5 μm, fluorescent O_2 $^1\Delta$, nighttime NO_2, combination bands of CO_2 and O_3, and day to night invariant HNO_3 at 11.3 μm. Both spectra and radiance profiles of these emissions agree well with AFGL's LOWTRAN 4 and other local thermal equilibrium models below 40 km. From 40 to 15 km, several near infrared spectra of aerosol scattering were obtained on each of the four sunlit scans. These data will be used in conjunction with simultaneous photometer measurements to update the FLASH Monte Carlo scattering code.



The spectrum of the earth limb at night taken by SPIRE at a 40 km tangent altitude.

Auroral Studies: The first infrared emission measurements (1.5 to 23 μm) of the atmosphere above 50 km had been obtained by rocket probes in 1972. These experiments were launched out of Poker Flat, Alaska, under an AFGL/DNA sponsored program called ICECAP (Infrared Chemistry Experiments for the Coordinated Auroral Program). This program obtained auroral enhancements at 2.8 and 5.3 μm from nitric oxide, and 4.3 μm emission from carbon dioxide. Analysis indicates that the observed temporal and spatial behavior of the 4.3 μm auroral radiation can be explained by a mechanism involving vibrational excitation of nitrogen by direct electron impact, followed by a collisional resonance vibrational transfer to excite carbon dioxide, followed by emission by the carbon dioxide at 4.3 μm. This mechanism is complicated by repeated transfers of the vibrational energy back and forth between nitrogen and carbon dioxide, and by repeated absorption and emission by the carbon dioxide, which is optically thick enough below 90 km to ensure that the 4.3 μm radiation will be absorbed and re-emitted many times as it escapes from the atmosphere. Another significant result caused by the absorption and re-emission of all the radiation is that the time response for the auroral 4.3 μm emission is of the order of 5 to 10 min after the electron deposition.

To test further the complex 4.3 μm radiation transport theory, an auroral dynamics experiment was conducted on 26 October 1978. Two rocket probes, one carrying the most sensitive cryogenic radiometer yet built and one monitoring the auroral particle flux and local electron density profile, were launched into and over a bright stable auroral arc. The first probe carried three co-aligned radiometric channels: 4278 Å for instantaneous energy deposition, 2.7 μm for OH airglow and NO overtone (auroral produced), and 4.3 μm for CO_2 (ν_3) emission. In addition, supporting ground based optical data and incoherent back-scatter radar measurements were made.

The 4278 Å (N_2^+ first negative band, 0-1) photometer measurements showed that the rocket instruments were viewing a fairly bright auroral region throughout the entire rocket ascent. The precessional motion of the rocket axis caused maxima to be observed at 78, 98, and 112 km, where the rocket axis swung through nearest the direction of the brightest portion of the arc. The magnitude of the first two maxima of about 3 kR would correspond to a 5577 Å auroral intensity of around 20 kR. The slight drop off with altitude and much less variation with respect to rocket precessional motions indicate that the rocket was ascending through some of the auroral deposition region vertically, and at the same time was moving into the brighter region due to the horizontal motion of the rocket. The observed intensity of over 2 kR at apogee indicates that a substantial portion of the aurora still remained above the rocket. The preliminary results from the Chatanika radar indicate that the auroral deposition region was relatively high (around 120-km peak). On descent the rocket passed through the main arc region horizontally with a drop off of intensity at about 102 km. At 95 km the descent value was an order of magnitude lower than that on ascent.

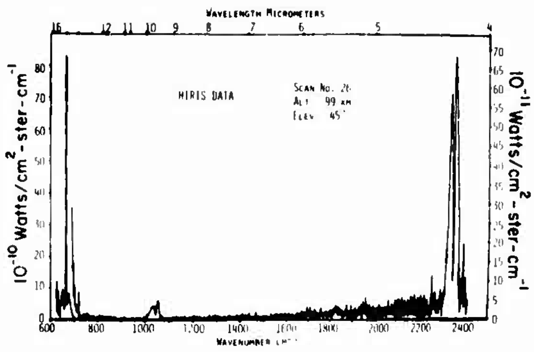
The measured ascent profiles of the 2.7 μm emission generally follow the energy deposition as monitored by the 4278 Å photometer. The region up to about 90 km shows a fall-off of about a factor of 2 superimposed on a structure very similar to the photometer data. The descent 2.7 μm data also show structure closely related to the 4278 Å results except the region below 90 km looks like the ascent 2.7 μm data.

Comparison with the equivalent N_2^+ 3914 Å emission, which is commonly used to indicate the instantaneous energy deposition, gives a ratio of about 7 photons of 2.7 μm per photon of 3914 Å emission. This value is nearly independent of altitude above 85 km. On an energy basis this means that about equal energy is converted to the 2.7 μm band and the 3914 Å band over the range from 85 to 122 km.

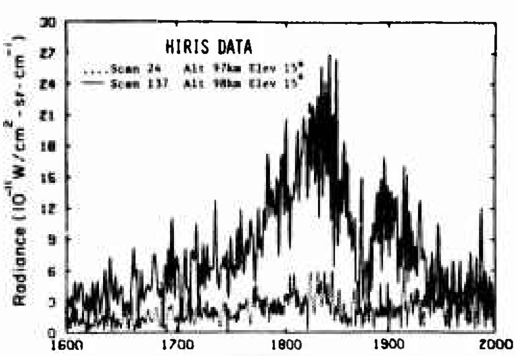
The measured ascent 4.3 μm profile radiation, in general, does not follow the instantaneous energy deposition as monitored by the 4278 Å photometer. At 100 km the ascent zenith radiances of the 4.3 μm emission are nearly an order of magnitude brighter than measured on rocket descent with the two profiles converging below 85 km.

A quick comparison of these results with previous investigation indicates that at 95 km, the intensity on ascent would lie between the value found on an IBC II+ auroral arc and quiet values, whereas the descent value was near that of the quiet background.

The first high resolution spectra of an auroral event were obtained by the cryogenic interferometer-spectrometer,



Atmospheric spectra obtained by HIRIS on the upleg from 99 km altitude (105 seconds after launch) with the sensor viewing at an elevation of approximately 45 degrees (from horizontal). The obvious spectral features are due to the 15 μm ν_3 fundamental of CO_2 at 2350 wavenumbers. For presentation purposes there is a split scale at 700 wavenumbers; the left scale applies to the 15 μm CO_2 band which has a peak spectral radiance value of 83×10^{-10} W/cm^{2}sr wavenumbers for the Q branch and the right hand scale applies to the rest of the spectrum (700 to 2500 wavenumbers).



A selected portion (160 wavenumbers to 2000 wavenumbers, the fundamental $\Delta v = 1$, region of nitric oxide) of two spectra obtained by HIRIS at approximately the same sensor altitude, 98 km, and the same elevation angle, 15 degrees, but observed at different times and, consequently, representing different auroral conditions. The lower spectrum was obtained during the upleg at 102 sec after launch (3 sec before the scan shown above) viewing at an azimuth angle of 64 degrees (northeast). The upper curve was obtained during the downleg (+255 sec) viewing an azimuth angle of 247 degrees (southwest).

HIRIS. This rocket-borne sensor was launched into an auroral breakup from Poker Flat, Alaska, on April 1, 1976. The interferometer covered the spectral region, 600 to 2500 wavenumbers with approximately 2 wavenumber resolution. The flight was designed to view vertically from 96 km on the upleg to an apogee of 125 km and to 70 km on the downleg. However, the attitude control system failed to hold the sensor in a vertical position after initiating a turnover command (the interferometer was integrated in a down-looking configuration). This resulted in the payload rotating at 10.5 deg/sec and performing six full rotations, vertical to down-looking, during the flight.

The auroral activity was documented by all-sky photographs obtained by the University of Alaska, scanning and fixed photometers by Utah State University and bakkscatter radar (Chatanika site) by Stanford Research Institute. These diagnostic data clearly show a Class III arc (100 kR) in the field of view during the time of the downleg spectrum (viewing southwest). The conditions for the upleg data show a more patchy auroral environment with less electron deposition occurring in the line of sight. The previously reported auroral enhanced infrared emissions did not cover the wavelength region beyond about 5.3 μm and were of too low resolution to identify NO uniquely as the principal radiator.

Two spectra obtained near 98 km and 100 km were analyzed to obtain relative NO(v) popuwations and estimates of NO(Δv=1) fluorescence efficiencies. The vibrational population distributions were derived by a spectral simulation technique using a least squares method to determine the best match between computed and measured spectra. Because of the high resolution of the measurement, the accuracy of the line frequency calculation was carefully established.

The derived vibrational population distributions were found to be non-Boltzmann with pronounced local minima at v = 2 and exponential "tails" (v = 3-6) characteristic of temperatures of 2500 to 3500 K. The rotational temperature was determined to be approximately 235 K, which is representative of the local kinetic temperature at approximately 100 km. Populations of vibrational levels above v=6 could not be determined due to the noise level of the measurements.

The integrated NO (Δv=1) band intensities for the two data sets were used to deduce NO (v) column densities along the line of sight and fluorescence efficiencies for the fundamental band. The fluorescence efficiencies estimated from the two scans are in fair agreement in view of the considerable variations of auroral intensity sampled by the detector during each scan; the preliminary results indicate that, at altitudes near 100 km, roughly, 2 to 5 NO (Δv=1) photons are emitted per ion pair formed in the aurora.

A group of optical instruments for aircraft-based auroral measurements consisting of a multiple field infrared radiometer, a scanning photometer, and a low light level television is scheduled for installation into the NKC-135 Infrared Flying Laboratory in March 1979. This new system will enable spatially correlated visible and infrared measurements of infrared and visible aurora at a footprint size of 0.5 km. The infrared radiometer has a detector and optical system cooled by liquid nitrogen and a window and baffle which is cooled and flushed by cold nitrogen gas. This results in an order of magnitude increase in sensitivity compared to instruments with warm optics flown previously.

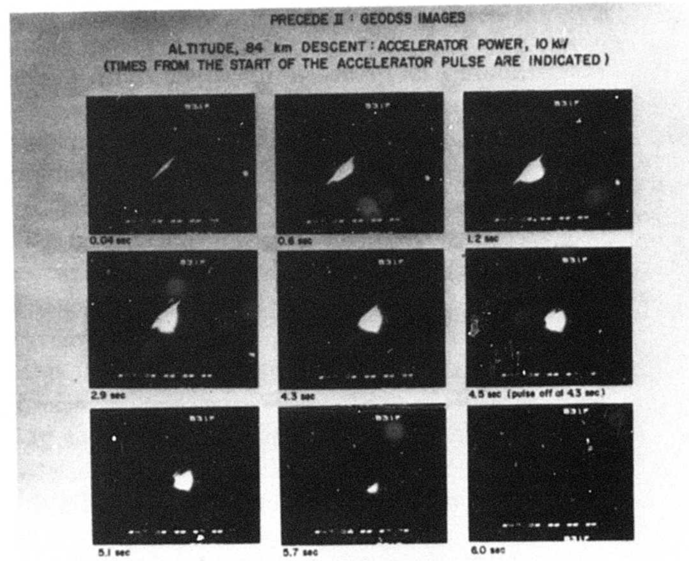
The data from these visible and infrared instruments will be used to determine the spatial and temporal characteristics of infrared aurora at selected wavelengths and to determine the spatial and temporal correlation between infrared and visible aurora.

The development of a totally liquid nitrogen cooled Michelson interferometer has continued and the installation of a vibrationally isolated nitrogen cooled interferometer into the aircraft is scheduled for early

1980. This will enable spectral measurements of auroral emissions out to 5.5 μm.

EXCEDE: The AFGL/Defense Nuclear Agency program called EXCEDE uses rocket-borne electron accelerators to simulate atmospheric processes induced by the deposition of energetic electrons as in auroras and high altitude nuclear detonations. The primary scientific interest is the investigation of the detailed production and loss processes of various excited electronic and vibrational states resulting in optical and infrared emission as energetic primary electrons and their secondary and all subsequent generation electrons are stopped in the atmosphere. The EXCEDE experiment uses pulsed rocket-borne electron accelerators with well-defined excitation conditions of electron energy and power, deposition volume, deposition altitude and dosing duration to provide measurements of time dependent optical and infrared emissions which are interpreted in terms of chemical processes, reaction rates, and photon yields. These data are utilized in various computer codes to calculate optical/infrared backgrounds for auroral and nuclear disturbed atmospheres. The codes assess the effects of enhanced atmospheric backgrounds on optical and infrared systems.

On December 13, 1977, PRECEDE II, one of a series of artificial auroral experiments in the EXCEDE program, was launched from the White Sands Missile Range, New Mexico, at 05:50 UT. PRECEDE II was designed to serve as an engineering test of an electron accelerator module providing a pulsed 3 kV, 7 A electron beam, to provide an engineering test for a newly designed liquid nitrogen cooled rocket-borne infrared Michelson interferometer, and to observe the ultraviolet and visible emissions induced in the night sky by the rocket-borne electron source with a number of ground based imaging, spectrographic, and photometric instruments. The accelerator, 38 cm in diameter, 91 cm long, and weighing 160 kg, was designed to pro-



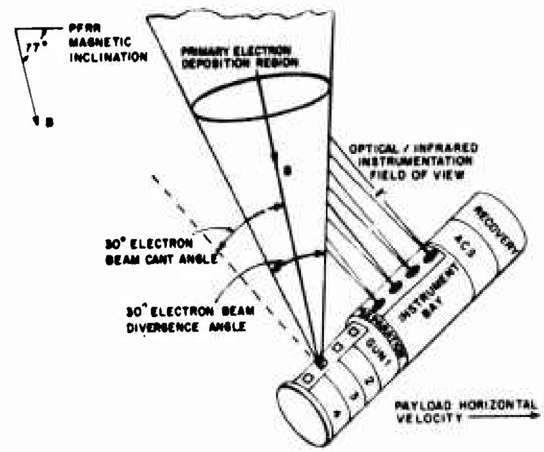
Images of the electron induced optical emissions induced in the night atmosphere by the rocket-borne electron accelerator in the PRECEDE II artificial auroral experiment. The emission developing slowly after the accelerator is pulsed on and persisting after the accelerator is pulsed off at 4.3 seconds is due to the long lived O(^{1}S) auroral green line.

vide a 20-kW beam of 3-kV electrons. A pulse period of 6 sec composed of a 4.3-sec beam on and a 1.7 sec beam off component, was intended to be repeated for the duration of the experiment, anticipated to be on the order of 3 min, assuming nominal rocket performance. The PRECEDE II launch was designed, in part, as an engineering test of a prototype electron accelerator module to be used on the subsequent EXCEDE spectral experiment. The accelerator used two tungsten filaments directly heated to approximately 2800 K.

The accelerator door was opened, filaments heated and high voltage applied 108 sec after launch, at an upleg altitude of approximately 83 km. The accelerator arced due to high voltage breakdown within the accelerator structure for approximately 30 sec, until the payload achieved an altitude of 97 km at 138 sec after lift-off. A latch-out protection circuit limited the maximum energy dissipation during the arcing and prevented catastrophic failure due to fusing of any accelerator components. At approximately 138 sec after launch, the accelerator produced a 4.3-sec pulse of 3-kV electrons depositing 20 kW into the night atmosphere. The electron induced ultraviolet and visible emissions were readily recorded by the ground based optical instruments which included film cameras, telephotometers, and image intensified spectrographs.

The accelerator power output showed slight loading characteristics during a given pulse and the power output decreased from approximately 20 kW at 138 sec after launch (97 km on payload ascent) to approximately 13 kW at 212 sec (95 km on payload descent). At lower descent altitudes, the accelerator continued operation, pulsing sporadically and providing an electron beam of several kilowatts to a descent altitude of approximately 64 km. The PRECEDE II rocket flight was a severe test of an accelerator module to be launched on the EXCEDE SPECTRAL experiment.

The two major innovations in the proposed EXCEDE SPECTRAL experiment are: (1) a significant increase in the power of the rocket-borne electron accelerator; and (2) the addition of optical and infrared spectral instruments to record detailed band profiles rather than photometric and radiometric instruments that isolate specific wavelength intervals as used in the earlier launches. The proposed nominal electron-accelerator power is 120 kW (3 kV, 40 A) using 4 electron-gun modules each providing a 10 A beam. Rocket-borne spectral instrumentation includes two grating spectrometers, a Michelson interferometer using liquid nitrogen cooled optics to provide the minimal detectable radiance as limited by thermal emissions of the instrument and two circular variable filter spectrometers operating at both liquid nitrogen and liquid helium temperatures. The optical bandwidth of the spectral sensors extends from approximately 0.15 to 25 μm. The EXCEDE SPECTRAL experiment is expected to provide sufficient resolution to identify uniquely the species emitting in the UV, visible and IR under experimental conditions that simulate auroral and nuclear disturbed atmospheres.



Payload orientation for the EXCEDE SPECTRAL experiment with only electron gun module 3 shown operating. The attitude control system maintains the indicated position in pitch, yaw and roll for the duration of the experiment.

Analysis of the time dependent O (^{1}S) 5577 Å emission induced in the night atmosphere by a pulsed rocket-borne electron accelerator in the initial EXCEDE launches has been completed. Energy transfer from the $N_2(A^3\Sigma u^+)$ state to $O(^3P)$ is the principal $O(^1S)$ production process in the 95- to 160-km altitude range, accounting for as much as 75 percent of the total $O(^1S)$ production at some altitudes. The $O(^1S)$ production and loss processes inferred from the EXCEDE experiments have been used to compute the time dependent $O(^1S)$ auroral emission rate as a function of altitude in a model aurora. The accurate reproduction of auroral $O(^1S)$ emission rates by the model calculations is considered a significant test of validity of the $O(^1S)$ production and loss processes determined in the initial EXCEDE launches.

Optical Infrared Code (OPTIR): A computer code and modeling effort, OPTIR, describes the optical infrared characteristics of natural and high energy sources in the atmosphere. The code is particularly designed to model nuclear detonations in the atmosphere and predict their effects on optical/infrared systems. Modular subelements of the OPTIR code have been adapted for specific radiation and energy deposition applications, such as low-altitude burst signatures (TACTIR), auroral deposition and radiative characteristics (OPTAUR), and observations by surveillance systems (SIMDRIV).

Computer code models have been developed for infrared radiation sources in the 2.0 to 5.0 μm region arising from nuclear bursts in the atmosphere. Such models include the infrared chemistry sources in regions affected by the passage of strong shocks, thermal pulse output from nuclear fireballs and spatio-temporal variations in emissions from beta tubes. Scaling laws of fireball signatures in the visible and infrared spectrum as a function of wavelength and time after burst have been developed. The OPTIR capability has been used effectively in programs to determine the nuclear effects on optical/infrared systems.

Instrumentation Development: Detailed knowledge of the spectral characteristics of background radiation and of atmospheric emission and absorption is required to design high sensitivity sensors for optimum performance. Concurrently, research on techniques to enhance the sensitivity of sensors is being performed. Multiplex/high-throughput techniques can yield the required detailed spectral information and, at the same time, be used to develop more sensitive sensors.

Research is being carried on leading to the development of a state-of-the-art high resolution (0.1 wavenumber) cryogenic interferometer for field measurements. New techniques, such as the Spectrometer Interferometer with Selective Modulation (SIMS being its French acronym), are being studied. The potential of this technique lies in the fact that the spectrum is obtained directly without Fourier transformation, while still using a scanning interferometer of high throughput. It also should prove to be a more stable instrument since the two interfering beams use the same optical components.

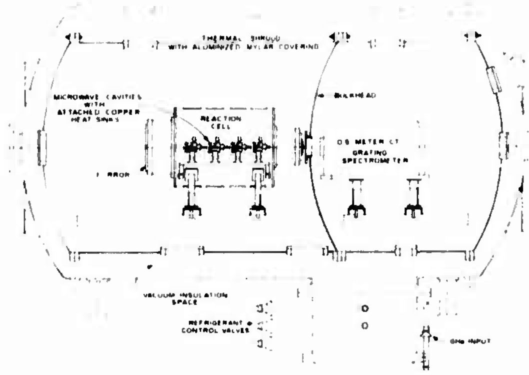
The new AFGL facility, called COCHISE (Cold Chemi-excited Infrared Simulation Experiments), implements detection technology and concepts initially developed for space surveillance systems, achieves infrared detection sensitivities up to six orders of magnitude better than available in any other laboratory, and concurrently provides a truly novel low-pressure, "wall-less" capability for simulation and study of high-altitude phenomena. Experiments are conducted entirely within a large cavity held at 20 K by a closed-cycle gaseous helium refrigeration system. Part of the refrigeration capacity is also used to provide a cryopumping capability within a closely temperature-controlled reaction chamber located inside the large 20 K cavity; an infrared scanning monochromator also stationed in the 20 K environment measures the radiation produced by processes occurring in the cryo-pumped hyper-fast-flow reaction volume. By reducing to a totally negligible level the thermal background radiation, an IR detectivity has been achieved which permits the observation of emissions from excited species with number densities as low as 10^6 cm^{-3}. Operation of the facility is augmented by an unusually large and complex minicomputer system which executes automatically a multitude of control, measurement, and analysis tasks; the computer system is hard-wired to and totally dedicated to support of the COCHISE facility.

In initial applications, experiments have been conducted by mixing the products from a synchronized set of electrodeless microwave discharges with non-excited target gases; with a contact time well under one msec, the radiation observed is representative of the initial undisturbed product molecule vibrational distribution. A quantitative definition of the IR photon yield from chemi-excited nitric oxide produced by $N(^2D) + O_2$ has been completed and it has been established that 27 percent of the energy released in this reaction is converted to vibrational excitation of the NO product molecule. By experimentally defining the quantum details of the process, which produces IR radiation in the 2.7- and 5.3-μm regions, its altitude dependence in the atmosphere has also been determined. Data have also been collected in the COCHISE program which begin to define the extent to which the 10- to 12-μm atmospheric "window" can be degraded by ozone infrared emission; in this case, it is the recombination of atomic oxygen (via the process $O + O_2 + M \rightarrow O_3 + M$, yielding vibrationally excited ozone) which is being subjected to scrutiny.

Development of ultraviolet resonance absorption and tunable laser diagnostics for ionic and non-radiating species is well under way. This step will substantially enhance the value of COCHISE for a broader range of problems.

IR Emission from Electron Excited Air:

Electron excitation and subsequent energy transfer processes by atmospheric species occur in the upper atmosphere either naturally as in the aurora or following a high altitude nuclear event. Detailed information concerning these exchange processes, which control the radiative state of the atmosphere, are obtained by using our laboratory simulation facilities and measuring the visible and infrared emission produced by energetic electron irradiation of atmospheric gases. Excitation is accomplished by electrically pulsing an electron beam of 0-20 mA over a 5000 to 50,000 V energy range into a target chamber containing atmospheric gas mixtures at pressures of 1/1,000,000 to 1 atmosphere.



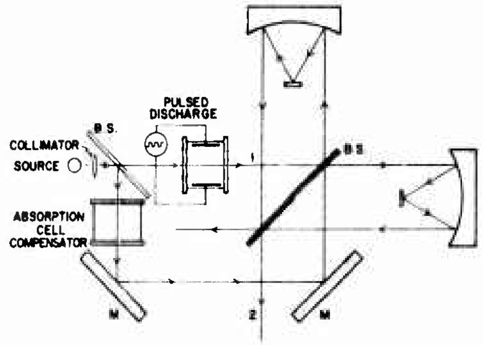
Scale drawing of COCHISE facility chamber; overall length is nearly 11 feet. Only the major components are shown here. System cooling is provided by a 0.5 kw closed-cycle gaseous helium refrigerator.

Recent experiments have concentrated on determining the dynamic behavior of excited gases by observing the evolutionary history of the radiation produced during and after electron impact. The measurement technique of Fourier Time Resolved Spectroscopy is used to obtain the time dependence of the infrared emissions. This technique, developed at AFGL, is based on time gating the signal of a Michelson interferometer-spectrometer at corresponding sampling positions of the interferometer stroke to obtain a series of time sequenced interferograms. Fourier tranformation of the series of interferograms gives the entire infrared radiation evolution of the excited gas.

Typically, the radiation to be observed is weak; hence, the throughput and multiplex advantages of Fourier interferometry are essential to perform the required spectral measurements. The capability of our time-resolved technique has been improved by utilizing a minicomputer to control the experiment and record the interferograms. As the interferometer mirror is scanned, its motion dictates both the computer processing and interferogram recording. With this arrangement the ultimate time resolution achieved is the limit of the response time of the infrared detector.

A background optical suppression scheme (BOSS), conceived at AFGL, is being pursued for use in various applications. It has the potential of allowing the detection and spectral signature measurements of faint targets immersed in interfering background radiation. Laboratory data have been obtained which demonstrate a background suppression ratio of about two orders of magnitude.

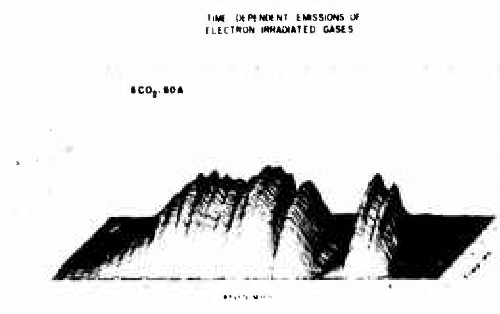
Several highly sophisticated laboratory measurement efforts support and add to the extensive field measurement and modeling programs discussed. These include high resolution spectral measurements of molecular parameters, study of specific atomic and molecular excitation processes responsible for infrared emission in the upper atmosphere, infrared emission from molecules excited by electrons, and investigation of high velocity collisions between gaseous species. Such basic research studies provide the data fundamental to our scientific understanding of the measurements on atmospheric IR transmission and emission (backgrounds) and particularly to the developments of the codes and models describing these atmospheric phenomena.



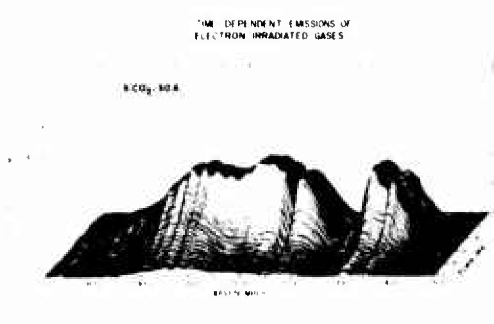
A double beam scheme applied to Michelson interferometer to nullify the effects of windows. The beam labeled 1 contains wanted information, the absorption spectrum of the discharge, plus a contribution from the cell windows which is not wanted. The portion reflected upwards at the dielectric beam splitter differs in phase by π from the portion transmitted forward. Another beam, containing only the unwanted cell spectrum is reflected by mirrors and brought to the beam splitter on its other side. The portion reflected to the right undergoes a phase change of π and so is out of phase with the contribution coming from the discharge and if the amplitudes are adjusted properly, will cancel out the cell signal. Similarly, the upwards going beams are also in anti-phase. The final beam, 2 is thus free of the effects of the cell, and contains the absorption of the gas only.

Cryogenic IR Chemi-Excitation Experiments: The laboratory has built and is now operating an awesome new experimental facility to study specific atomic and molecular excitation processes which are important sources of atmospheric IR radiation, and which could compromise the performance of DoD IR surveillance systems. Detailed definitions of the microscopic processes which control production and relaxation of energetically excited species are required, to make reliable predictions and assessments of atmospheric radiation perturbations resulting from natural and artificially induced atmospheric disturbances. The long radiative lifetimes typically associated with molecular vibrational transitions demand that experiments be operated at pressures low enough to simulate upper atmosphere densities and simultaneously not be compromised by spurious surface effects such as wall collisions.

Time-resolved infrared measurements have been performed on carbon dioxide and various gas mixtures subjected to electron bombardment. Fluorescence of the gas mixtures in the 3 to 6 μm spectral region is predominantly due to the carbon monoxide fundamental bands up to the nineteenth vibrational level and the fundamental 4.3 μm band of carbon dioxide. By employing the electron beam in a short pulse, low duty cycle mode, the rise and decay behavior of the spectrally resolved fluorescence has been determined. Observation of the global radiative spectrum has proved invaluable in determining and quantifying the relevant electron, ionic and neutral chemical kinetics occurring in the irradiated system. Specifically, it has permitted the origin of highly excited carbon monoxide to be determined, that is, ionization of carbon dioxide followed by disassociative electron recombination. Based on the known energy input, the fluorescence measurements show that 5 percent of the energy deposited in the gas appears as excited carbon monoxide with, on the average, one vibrationally hot molecule being produced per ion pair. The decay of the infrared emission is characterized by relaxation rate constants with a vibrational quanta being communicated in a step-down process from carbon monoxide to carbon dioxide. The rate constants for sixteen levels have been determined from data collected. Additionally, experimentally determined values for the fundamental Einstein coefficients for emission have been obtained on levels seven through twelve. This is the first determination by direct measurement and the values appear to be in good agreement with theoretical estimates.



Decay of excited species observed after pulse termination. The decay of the vibrationally hot CO (T_v approximately 20,000 K) and CO_2 may be followed as a function of time and vibrational level.



Excitation buildup observed during electron pulse. The pulse (32 kV, 1 ma) is terminated after 4 msec. The buildup of CO in the region 2250 to 1800 wavenumbers, and CO_2 in the region 2400 to 2300 wavenumbers is clearly shown.

A major effort has been directed toward determining the mechanisms responsible for producing 2.7 μm radiation in the quiescent and aurorally disturbed atmosphere. The generally accepted thesis is that a majority of emission is due to the first overtone vibration rotation bands of nitric oxide. Several sets of measurements by various atmospheric probes are known to be inconsistent with the nitric oxide model. Ratios of emission between the fundamental and first overtone bands appeared too small and carbon dioxide combination band emission was offered as an explanation. This possibility has been explored in our laboratory by spectrally resolving the 2.7 μm emission produced by electron irradiated air which contains carbon dioxide and comparing similar measurements performed on air from which the carbon dioxide has been removed. Spectral measurements established that the combination bands are 1/25th as strong as the 4.3 μm band, and, hence, are not responsible for the observable emission at the shorter wavelength. The laboratory measurements also show that the nitric oxide formed is highly excited and suggests that a possible explanation of the observed anomaly is due to incorrect transition probabilities or hydroxyl emission.

To study the IR emission at longer wavelengths (5 to 25 μm) and lower pressures, a large tank, 4 1/2 feet in diameter and 15 feet in length, is used. At these wavelengths, the emission by the room surroundings is larger than that produced by electron excitation of the experimental gases. To overcome this thermal background, the entire internal surface of the tank, transfer optics and IR instrumentation are cooled to liquid nitrogen temperatures. With this added temperature control, the sensitivity of the measurements is effectively increased by one thousand or more, and measurements which were previously impossible are now possible.

Molecular Beam Studies: High velocity collisions occurring at high altitudes (above 300 km) between plume and atmospheric gaseous species are investigated in the molecular beam facility. At these altitudes the main atmospheric species is atomic oxygen. For lower altitudes, interaction with molecular nitrogen and oxygen become significant. Consequently, the experimental efforts are directed toward production of fast beams for the species O, N_2 and O_2. For the permanent gases N_2 and O_2, the beam production technique used is the well-established method of isentropic expansion of a gaseous mixture from a heated supersonic nozzle. Beam velocities and their speed distributions are studied by time of flight measurements. Beam intensities of 5 x 10^{18} particles per steradian per second are readily achieved. In the early stages of this program, the plume particles (CO_2 and CO) were introduced into a gold-plated integrating sphere where they interacted with fast beams of N_2 or O_2. As reported, no signals were observed in this preliminary warm background experiment. Analysis showed that background temperature had to be considerably lowered to achieve higher signal-to-noise ratios. The major improvements undertaken were design and construction of a new liquid nitrogen cooled collision chamber, design and construction of a 2.4 to 4.8 μm CVF-spectrometer, and introduction of the target gases CO_2 and others in the form of another molecular beam flowing opposite to the fast beam of atmospheric species, in the so-called 180 degree geometry. These major improvements have finally been incorporated in the molecular beam facilities and the apparazus is now operational and producing significant measurements. Emission from CO_2 in the 4.3-μm band spectral region has been recorded following vibrational excitation of the ν_3 mode of CO_2 by molecular oxygen and nitrogen in an elastic collision with relative velocity ranging from 2 to 4.2 km/sec. Spectra have been obtained at all these velocities and data have been analyzed to obtain the extent of the rotational excitation in the observed modes and to extract cross sections for the collisions.

The LABCEDE tank showing the liquid nitrogen lines and controls.

For the study of the atomic oxygen collisions, a new beam source utilizing DC arc heating and isentropic expansion was designed and its construction is almost complete. After installation and diagnostics measurements, the reactions of CO_2 and H_2O with O atoms will be studied in detail.

Molecular Spectroscopy: A substantial laboratory program aimed at measuring the spectral parameters of atmospheric gases includes high resolution laboratory data on H_2O, CH_4 and CO_2 using a 2-meter path difference interferometer-spectrometer. Data have been obtained at room and at elevated temperatures. Upon analysis of such spectra, any discrepancies between calculations and measurements can be used to determine an improved spectroscopic data set. In addition, absorption data at 0.01 wavenumber resolution at 625 K were obtained. This high-resolution facility is being modified to allow the measurement of high resolution (0.005 wavenumber) spectra up to flame temperatures around 2400 C. High-resolution (0.1 wavenumber) stratospheric emission data of dominant and trace constituents will be obtained in future balloon flights using an advanced state-of-the-art interferometer. These measurements are being made to upgrade the HITRAN transmission model.

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AFGL-TR-78-0077 (March 1978)

Appendix A

AFGL PROJECTS BY PROGRAM ELEMENT

Program	Project Number, Title, and Agency	
61101F	ILIR	Laboratory Director's Fund
61102F	*DEFENSE RESEARCH SCIENCES*	
	2303G1	Upper Atmosphere Chemistry
	2303G2	Plume-Atmosphere Interactions
	2309G1	Earth Sciences and Technologies
	2309G2	Crustal Motion Studies
	2310G1	Infrared and Optical Techniques
	2310G2	Atmospheric Dynamics
	2310G3	Upper Atmosphere Composition
	2310G4	Infrared Non-Equilibrium Radiation Mechanisms
	2310G5	Cloud Physics
	2311G1	Energetic Particles and Magnetic Fields
	2311G2	Electrical Structure of Aerospace
	2311G3	Solar Environmental Disturbances
62101F	*GEOPHYSICS*	
	4642	Aerospace Radio Propagation
	6670	Meteorological Development
	6687	Stratospheric Environment
	6690	Upper Atmosphere Technology
	7600	Terrestrial Sciences
	7601	Magnetospheric Effects on Space Systems
	7659	Aerospace Probe Technology
	7661	Spacecraft Charging Technology
	7670	Optical/IR Properties of the Environment

In addition to the above continuing Air Force funded projects, AFGL participates in joint programs supported by the following agencies:

1) U. S. Air Force:
    - Air Force Avionics Laboratory
    - Air Force Technical Applications Center
    - Air Force Weapons Laboratory
    - Air Weather Service
    - Electronic Systems Division
    - Space and Missile Systems Organization
    - Ogden Air Logistics Center
2) Army
3) Advanced Research Projects Agency
4) Defense Mapping Agency
5) Defense Nuclear Agency
6) Department of Energy
7) NASA

Appendix B

AFGL ROCKET PROGRAM: JULY 1976 - DECEMBER 1978

Date	Launch Site	Vehicle	Experiment	Scientist	Results
3 Aug 76	WSMR	Aerobee 350	IR Earth Limbs & Zodiacal Light	B. Schurin T. Murdock	Success
21 Aug 76	KMR	Nike Hydac	10" Falling Sphere	A. Faire	Failure (V)*
31 Aug 76	KMJ	Nike Hydac	10" Falling Sphere	A. Faire	Sucess
21 Apr 77	WSMR	Aerobee 170	Extreme UV	L. Heroux D. Bedo	Success
18 May 77	KMR	Nike Hydac	Neutral Density	A. Faire C. Philbrick	Success
9 Aug 77	WSMR	Aerobee 150	Extreme UV	L. Heroux D. Bedo	Success
24 Sep 7	WSMR	Niro	Winds and Diffusion Temperature	W. Vickery	Success
24 Sep 77	WSMR	Paiute Tomahawk	Neutral Compo ition	C. Philbrick	Success
11 Nov 77	WSMR	Aries	Extreme UV, UV, Airglow Emissions, Infrared	A. McIntyre	Success
13 Nov 77	PFRR	Sargent	Atmospheric Radiations, Auroral Emissions, Infrared	J. Ulwick	Success

WSMR —White Sands Missile Range, New Mexico
KMR —Kwajalein Missile Range, Pacific Ocean
PFRR —Poker Flat Rocket Range, Alaska
WFC —Wallops Flight Center, Wallops Island, Virginia
CRR —Churchill Rocket Range, Manitoba, Canada

*(P) — Payload
*(V) —Vehicle

AFGL ROCKET PROGRAM: JULY 1976 - DECEMBER 1978

Date	Launch Site	Vehicle	Experiment	Scientist	Results
13 Dec 77	WSMR	Aerobee 170	Atmospheric Radiations, Auroral Emissions (Artificial)	R. O'Neil	Success
21 Jan 78	WSMR	Astrobee F	Ion/Electron Density	H. Cohen	Success
28 Feb 78	PFRR	Sargent Hydac	Auroral Emissions, Currents and Fields, Magnetic Fields	J. Ulwick	Success
5 Apr 78	KMR	Nike Hydac	Neutral Density	C. Philbjick	Failure (V)*
5 Apr 78	KMR	Nike Hydac	Neutral Density	C. Philbrick	Partial
16 May 78	WSMR	Aerobee 170	Extreme UV, Ion/ Electron Density, Airglow Emissions	L. Heroux	Partial
20 May 78	WFC	Nike Nike	Winds and Diffusion	A. Quesada	Success
22 May 78	WFC	Nike Nike	Winds and Diffusion	A. Quesada	Success
25 Jul 78	WSMR	Aerobee 150	Neutral Density	D. Bedo	Partial
13 Sep 78	CRR	Nike Nike	Winds and Diffusion	A. Quesada	Success
13 Sep 78	CRR	Nike Nike	Winds and Diffusion	A. Quesada	Success
15 Sep 78	WSMR	Nike Tomahawk	Ion Composition, Ion/ Electron Density	R. Narcisi	Success
19 Sep 78	WSMR	Aerobee 170	Ultraviolet, Extreme UV	D. Bedo	Success
26 Oct 78	PFRR	Nike Hydac	Auroral Emissions	J. Ulwick	Success
26 Oct 78	PFRR	Nike Javelin	Winds and Diffusion	J. Ulwick W. Vickery	Failure (V)*
26 Oct 78	PFRR	Nike Hydac	Aurora and Airglow	J. Ulwick	Success
29 Oct 78	PFRR	Talos-Castor	Aurora and Airglow	R. O'Neil	Failure (P)*
13 Nov 78	PFRR	Sergeant	Auroral Emissions	J. Ulwick	Success

APPENDIX C

Air Force Geophysics Laboratory

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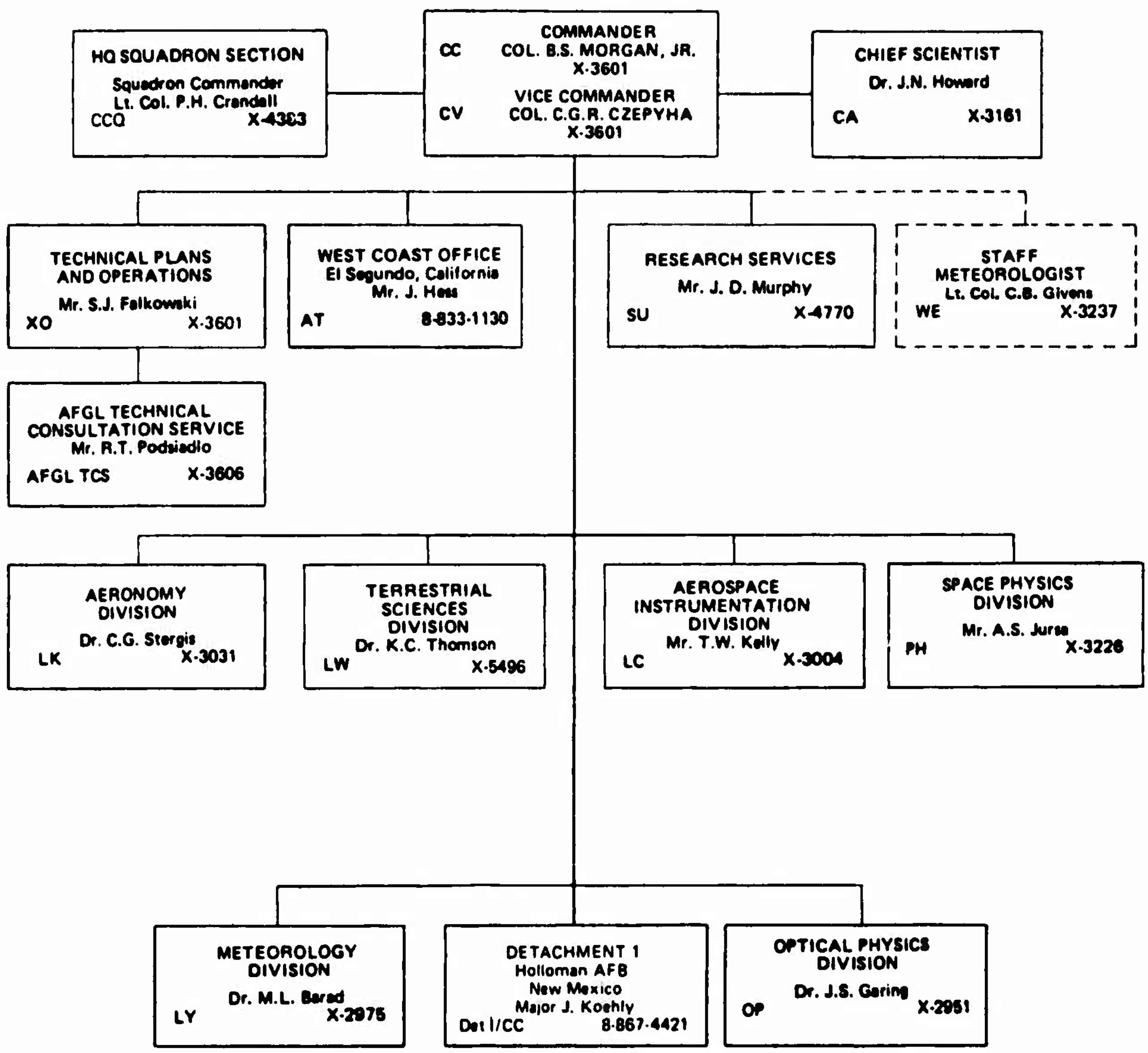

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